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Sadahito Uto, Masanori Ozaki, and Katsumi Yoshino

Molecular reorientation and deformation of a freely suspended ferroelectric liquid crystal film

Sadahito Uto[a)]
Department of Electrical Engineering, Faculty of Engineering, Osaka Institute of Technology, 5-16-1 Omiya, Asahi-ku, Osaka 535-8585, Japan

Masanori Ozaki and Katsumi Yoshino
Department of Electronic Engineering, Faculty of Engineering, Osaka University, 2-1 Yamada-Oka, Suita, Osaka 565-0871, Japan

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A study of the deformation of a freely suspended ferroelectric liquid crystal film induced by an alternating electric field has been carried out. A notable peak of the magnitude of the deformation was observed at the damping frequency of the molecular reorientation. A deformation that depends on the polarity of the applied field was observed in the frequency range higher than the damping frequency of the molecular reorientation. © *1999 American Institute of Physics.*
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Freely suspended (FS) films of ferroelectric liquid crystal (FLC) have recently attracted much attention as thin two-dimensional liquid crystal systems,[1–4] because they have a layered structure and their thickness can be varied from only two layers to several thousands layers. A FS film is easily deformed by the change of pressure of air,[5] and a mechanical vibration can be induced by an alternating electric field.[6] In this letter, the molecular reorientation and the mechanical deformation induced by the alternating electric field was investigated.

A ferroelectric liquid crystal (Chisso, CS-1029) is used in this study. This sample has a chiral smectic *C* phase between −18 and 72.9 °C, and its spontaneous polarization P_S is 41.3 nC/cm^2 at 25 °C. All experiments were carried out at 35 °C.

The FS film was prepared across two metal blades. Two polyethyleneterephthalate (PET) sheets were set between the blades. The sample was loaded in the square free area surrounded by the blades and the PET sheets. One of the PET sheets can slide along the blades to expand the FS film. These blades were also used as electrodes to apply an electric field to the FS film. The distance between the electrodes was 3 mm and the expanded square area was 9 mm^2. The freely suspended film was horizontally settled on an optical bench.

In the freely suspended ferroelectric liquid crystal (FSFLC) films, smectic layers are parallel to the film surface, so that the molecules can be oriented around the axis perpendicular to the film on the tilt cone. The molecular reorientation was estimated from an electro-optic measurement. For the electro-optic measurement, a semiconductor laser beam ($\lambda = 670$ nm) impinged on the FS film with incident angle of 12.6° which coincides with the tilt angle and is perpendicular to the applied field after passing through a polarizer, shown in Fig. 1(a). The polarizer was adjusted in such a way that the polarization direction made an angle of 45° with respect to the incident plane of the FSFLC film. The transmitted light was detected by a photodiode after passing through an analyzer. The analyzer and the polarizer crossed each other.

The film thickness was determined by an evaluation of the phase shift in the FSFLC film due to birefringence. For the determination of the thickness, the principal refractive indices of CS-1029 were required but have not yet been measured, and so we used the common values for FLC of 1.49 and 1.65 for ordinary and extraordinary light, respectively. The thickness of the FS film used in this study was about 24 μm.

The deformation of the FSFLC film was observed by reflection from the film surface. The deformation of the film causes a scanning of the reflection beam, and it can be sensed by the photodiode. However, not only the deformation but also the change of reflectance according to the molecular

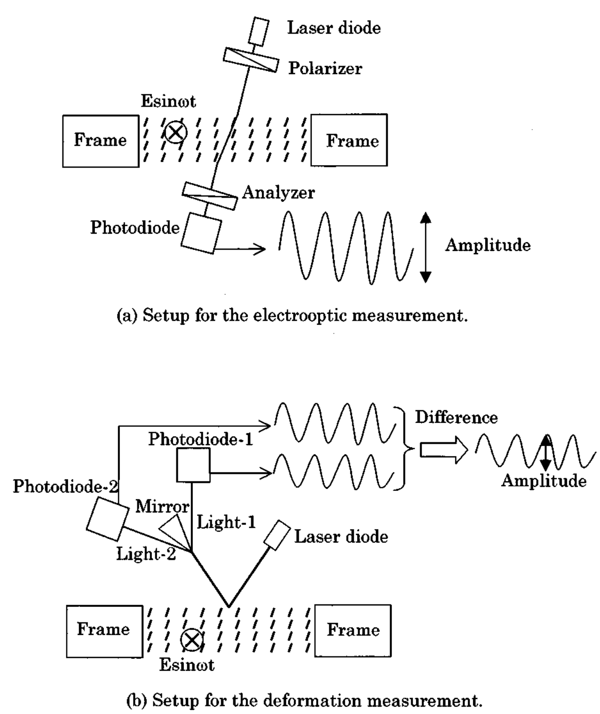
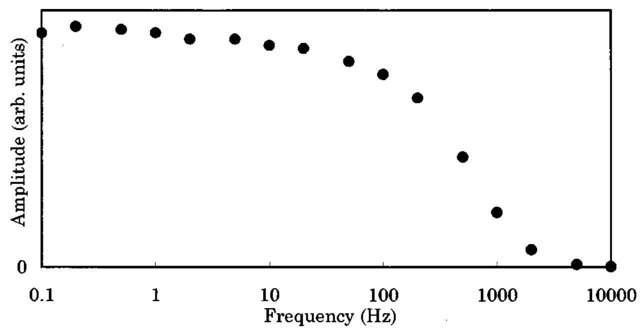
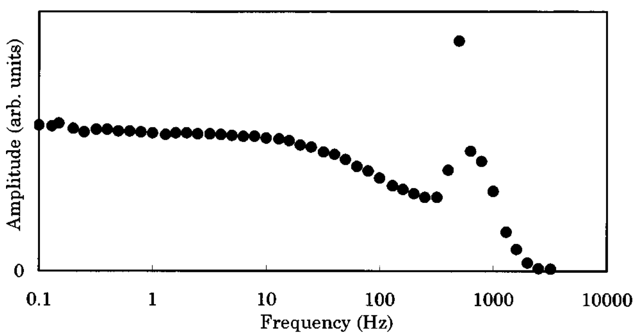


FIG. 1. Cross section of the FSFLC film and experimental setups.

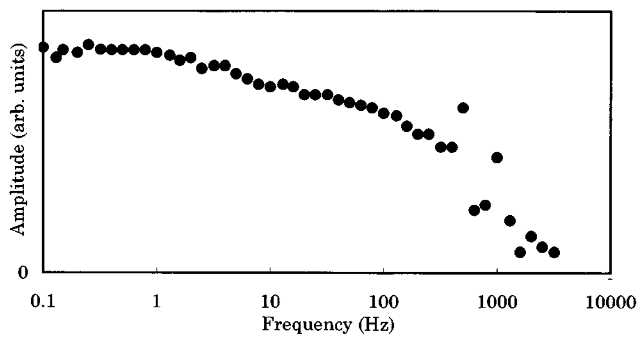
[a)]Electronic mail: suto@ee.oit.ac.jp



(a) Electrooptic effect.

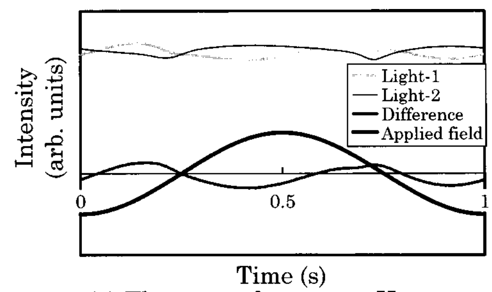


(b) Vertical scanning.

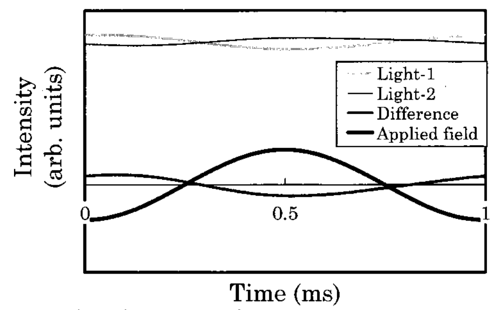


(c) Horizontal scanning.

FIG. 2. Frequency dependence. Applied field was sin wave of ±167 V/cm.



(a) The wave shapes at 1Hz.



(b) The wave shapes at 1000Hz.

FIG. 3. Wave shapes of the vertical scanning measurements. Applied field was sin wave of ±167 V/cm.

reorientation modifies the light reflection. In order to observe only the deformation, an edge-shaped mirror was used as shown in Fig. 1(b). The mirror divides the reflection light, and the divided two lights impinge on each photodiode-1 and -2. The change of the reflectance must cause a same change in the intensity of the light-1 and light-2. On the other hand, the scanning due to the deformation must cause a counter modification to them, so that a difference between the intensity of light-1 and light-2 contains only the signal of the deformation. The mirror in Fig. 1(b) is suitable for the measurement of a vertical scanning which is perpendicular to the film. It is possible to measure a horizontal scanning which is parallel to the film by tilting the mirror suitably.

Figure 2 shows frequency dependencies of the electro-optic effect, the vertical scanning, and the horizontal scanning of the reflection, respectively. The amplitude was defined as a magnitude of peak to peak value, as shown in Fig. 1. The amplitudes of them strongly depend on the frequency at about 500 Hz. The electro-optic effect starts to decay above 500 Hz, and there is a notable peak in the vertical scanning at 500 Hz. This means that, the strong deformation that induces the vertical scanning of the reflection light occurs in the FSFLC film at the damping frequency of the molecular reorientation.

It is well known that a mechanically vibrating freely suspended film has a spectrum of eigenvalues.[7] However, no harmonic resonance is observed, as shown in Fig. 2. In addition, the damping frequency did not change depending on the shape of the film; that is, the resonance observed at 500 Hz is intrinsic. This suggests that the vibration is not standing waves, which has a spectrum of the eigenvalues. The probable origin of the light scanning is change of the film thickness due to the electroclinic effect.

Figure 3 shows wave shapes of the vertical scanning measurement. The curve of the difference at a frequency below 500 Hz includes relatively large second harmonic components, as shown in Fig. 3(a). The deformation is not sensitive to the polarity of the applied field, so that it has second harmonic component. On the other hand, the curve at a frequency higher than 500 Hz scarcely has the second harmonic component and the fundamental becomes dominant, as shown in Fig. 3(b). This suggests the existence of another deformation, which depends on the polarity of the applied field. The origin of this deformation has not been clarified yet. However, a probable origin could lie in a change of the tilt angle induced by the electroclinic effect at a frequency which is too high to move the molecules on the tilt cone.

This work can be summarized as follows: (1) The deformation and the molecular reorientation of the FSFLC film were measured successively. (2) The notable peak of the deformation was observed at the damping frequency of the molecular reorientation. (3) The deformation that depends on the polarity of the applied field was observed in a frequency range higher than the damping frequency of the molecular reorientation.

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