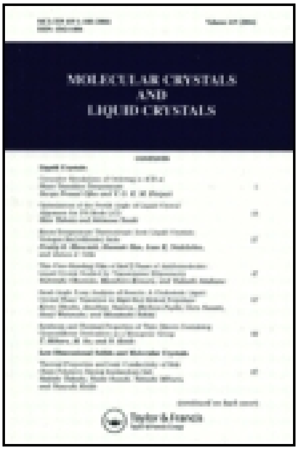

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Electromechanical Vibration Study in Freely Suspended Smectic Liquid Crystal

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Electromechanical Vibration Study in Freely Suspended Smectic Liquid Crystal

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Electric field induced vibration of a freely suspended film (FSF) of smectic liquid crystal has been studied as a function of temperature, applied field and film thickness. By the application of a sinusoidal electric field parallel to the film, not only a fundamental but also higher harmonics of the vibration has been observed. In particular, even the fifth-harmonics of the vibration is excited in ferroelectric liquid crystal (FLC). Electric field dependences of the vibration strength for fundamental and second-harmonic components have been found to be proportional to the electric field and to the square of the electric field, respectively. Temperature dependence of each component of the vibration strength has been also measured in FLC. The fundamental component of the vibration increases steeply around the phase transition temperature from the smectic A (SmA) phase to the chiral smectic C (SmC*) phase, while the second-harmonic component has taken the maximum strength just below the phase transition temperature. When the FSF was in the SmA phase, the optical response was smaller for the thick film compared with that for the thin film. Oppositely, in the SmC* phase, the film vibration was smaller for the thin film.

Keywords: freely suspended film; electromechanical effect

INTRODUCTION

A freely suspended film (FSF) has a layered structure and the thickness can be controlled from only two layers to several thousands layers. They have been intensively studied for the model of the two-dimensional system. In addition, the FSF is sensitive to the external field and can be easily deformed upon the application of external stress such as an acoustic vibration of the air.[1] On the contrary, the application of the electric field can excite a mechanical vibration on the FSF. These phenomena due to the coupling of the mechanical stress and electric field is called electromechanical effect, which is associated with the effect observed in piezo- and ferroelectric crystals. Although, in previous studies on the electromechanical effect, a sandwich cell of the liquid crystal has mainly been used,[2] we have reported that high frequency sinusoidal electric field induced the vibration in ferroelectric liquid crystal (FLC) FSF due to the electromechanical deformation.[3][4][5] However, the detailed study on the vibration in FLC FSF such as temperature dependence and nonlinear vibration has not been carried out. In this paper, we report the detailed characteristics of the FSF vibration excited by the electric field.

EXPERIMENTAL

Smectic liquid crystals used in study were 4-cyano-4'-octylbiphenyl (8CB) and ferroelectric liquid crystal mixture (Chisso, CS-1029). 8CB shows the smectic A (SmA) phase at room temperature. The spontaneous polarization and tilt angle of the FLC are 41.3 (nC/cm^2) and 25° at room temperature (25°C), respectively. FSF has been prepared in the SmA phase by means of spreading the liquid crystal over a rectangular small hole on the glass plate. Subsequently the film was kept undisturbed for several hours to get a uniform thickness of the film. For the estimation of the FSF thickness, the reflection spectrum from FSF surface was measured and theoretical curve fitting was performed.[6][7]

The scheme of the experimental setup is presented in Fig.1. The light source is a He-Ne laser (632.8nm). $\lambda/4$ plate was installed behind the laser to obtain circularly polarized light. Laser beam reflected from FSF surface is detected by a photo-diode via pinhole. Reflected light is modulated by the reflectance change of the film due to the molecular motion as well as the film vibration. In order to investigate only the film vibration, therefore, the contribution from the reflectance change must be subtracted from the total intensity change of the reflected light. Optical response is monitored using a Lock-in amplifier to detect fundamental and second-harmonic components with respect to the frequency of the applied filed.

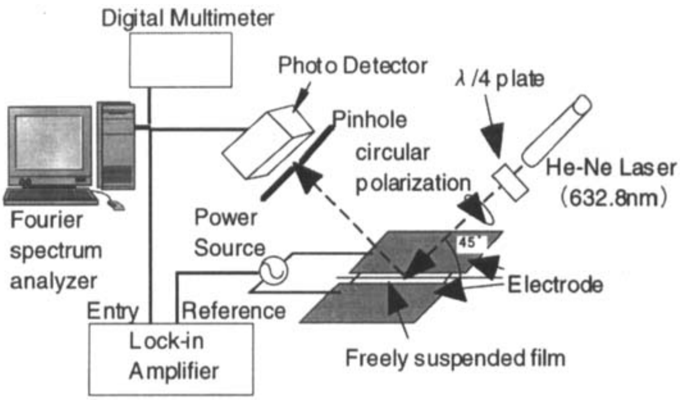


FIGURE.1 Experimental setup

The FSF of 8CB was prepared at 25°C and measurement was carried out at the same temperature. For FLC mixture, the film was prepared at 75°C and the measurement was performed at 75°C and 25°C which correspond to the SmA and SmC* phases, respectively.

RESULTS AND DISCUSSION

A. Smectic liquid crystal (8CB)

Figure 2 shows typical Fourier spectrum of the optical response for 8CB FSF upon a sinusoidal electric field at 1kHz. As is evident from this figure, the film vibration was excited upon applying the electric field. It should be noted that both fundamental and second-harmonic components were observed.

The strength of the film vibration depended on the electric field, E, as shown in Fig.3. The fundamental and second-harmonic components were proportional to electric field and square of electric field, respectively.

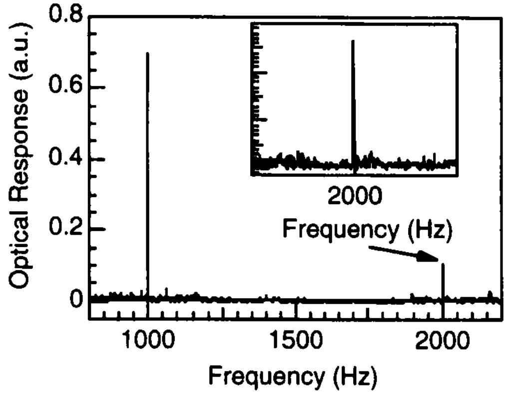
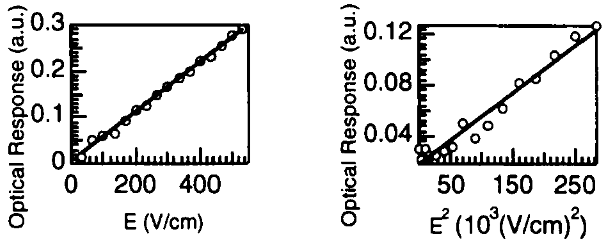


FIGURE.2 Fourier spectrum of optical response on 8CB FSF



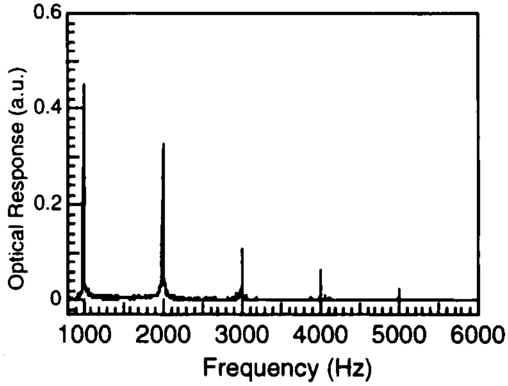
(a) Fundamental (b) Second-harmonic

FIGURE.3 Field dependence of optical response for the 8CB FSF

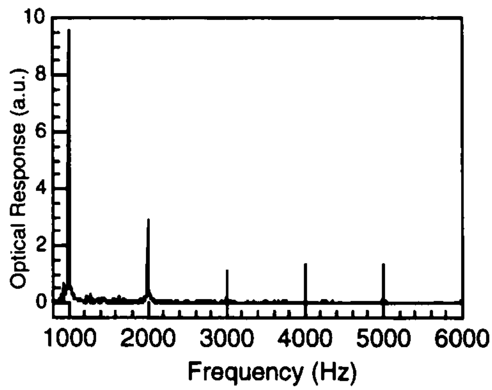
B. Ferroelectric liquid crystal

Figure 4 shows typical Fourier spectrum of optical response for FLC FSF upon the application of sinusoidal electric field whose frequency is 1kHz.

Both fundamental and second harmonic components were observed as the same manner as that for 8CB FSF. Additional components such as third and fourth harmonics can also be observed. It should be noted that the fundamental component of the optical response in the SmC* phase is about 10 times larger than that in the SmA phase. The optical response in the SmA phase for FLC FSF is equivalent to that for 8CB.Therefore the film vibration in the ferroelectric SmC* phase may be attributed to the different mechanism from that in the SmA phase.



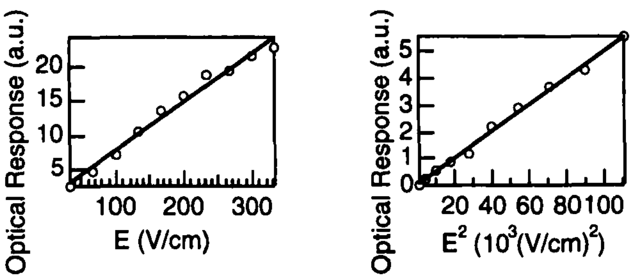
(a) SmA phase



(b) SmC* phase

FIGURE.4 Fourier spectrum of optical response for FLC FSF

Electric field dependences of the vibration strength for fundamental and second harmonic components in the SmA phase are shown in Fig.5.



(a) Fundamental (b) Second-harmonic

FIGURE.5 Field dependence of vibration strength in SmA phase

Fundamental and second-harmonic vibration show linear and quadratic behaviors, respectively. Field dependences in the SmC* phase are the same as those in the SmA phase.

The temperature dependence of fundamental and second-harmonic components of optical response is shown in Fig.6. The number of layers in this FSF was about 200 layers.

The fundamental component of the vibration monotonically increases with decreasing temperature below the transition temperature from the SmA to SmC* phases (Tc). On the other hand, the second-harmonic component is suppressed in the SmC* phase although it shows slight increase just below Tc. The fundamental component intensity was 5 times stronger than the second-harmonic one. It may be supposed that fundamental and second-harmonic components are associated with the Goldstone and soft mode relaxation behaviors, respectively. Except for the vicinity of the phase transition point, even in the SmC* phase, the second-harmonic component of the vibration is as weak as that in the SmA phase of 8CB. Therefore, the second-harmonic component of the vibration for FLC FSF originates from the similar mechanism to the 8CB.Namely, the molecular tilt in the smectic phase due to the soft mode resulted in the change of the film thickness. The change of film thickness due to the molecular tilt in the soft mode relaxation also comes about twice per one cycle of the electric field. This is independent of temperature. In order to clarify the detailed behavior of the fundamental component of the vibration, the thickness dependence of the vibration has been examined.

Figure7 shows the film thickness dependence of fundamental component of the optical response in the SmA and SmC* phases. In the SmA phase, only thin film less than 200 layers shows optical response. With increasing the number of layers, optical response decreased steeply and in thick film over 300 layers, the signal almost disappeared. On the other hand, in the SmC* phase, optical response increases with increasing the number of layers. This result in the SmC* phase may indicate that the bulk of the film mainly contributes to the vibration. Since 8CB FSF has only SmA phase, the optical response on 8CB FSF was 10 times smaller than FLC FSF.

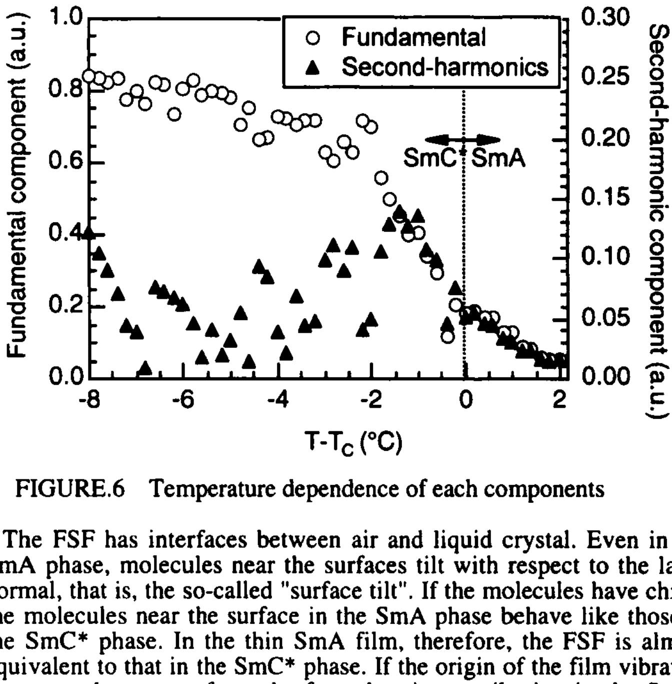
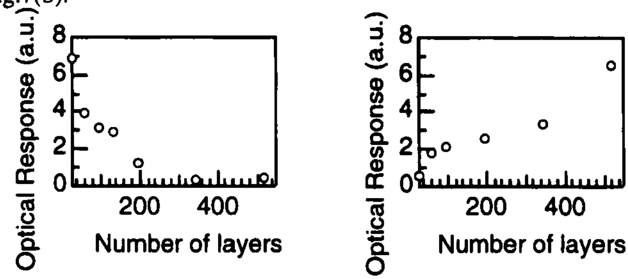


FIGURE.6 Temperature dependence of each components

The FSF has interfaces between air and liquid crystal. Even in the SmA phase, molecules near the surfaces tilt with respect to the layer normal, that is, the so-called "surface tilt". If the molecules have chiral, the molecules near the surface in the SmA phase behave like those in the SmC* phase. In the thin SmA film, therefore, the FSF is almost equivalent to that in the SmC* phase. If the origin of the film vibration is assumed to come from the ferroelectric contribution in the SmC* phase, the vibration should be effectively excited only near the surface in the SmA phase. With increasing layers, that is, with expanding the bulk regions in the film, the vibration is suppressed by the contribution of non-active region in the bulk in the SmA phase. On the other hand, in the SmC* phase, since the molecules tilt not only near the surfaces but also in the bulk, entire region in the film contributes to the film vibration, so that larger optical response is detected for thicker film as shown in Fig.7(b).



(a) SmA phase (b) SmC* phase

FIGURE.7 Thickness dependence of fundamental component of optical response on FLC FSF

The vibration mode in the FSF has been clarified. In this experiment, we prepared two types of geometries for the signal detection. As shown in Fig.8, two types of slits installed in front of the photo-detector were used to detect different reflection modes of the light from the film. Namely, the slits parallel and perpendicular to the incidence plane of the light allow us to detect the lights whose reflected angles are changed to the corresponding directions by the applied electric field. In addition, two directions of the rectangular frame suspending FSF were used as shown in Fig.8, in which the incidence plane of the light is parallel and perpendicular to the applied electric field. In these geometries, the frequency dependence was investigated.

In the frequency dependence of the film vibration of fundamental component in the SmC* phase, the peak of the optical vibration is observed around 3kHz. It should be noted that the peak appears only in the geometry in which the slit is perpendicular to the electric field. From this result, we clarified the vibration mode of FSF as shown in Fig.9.

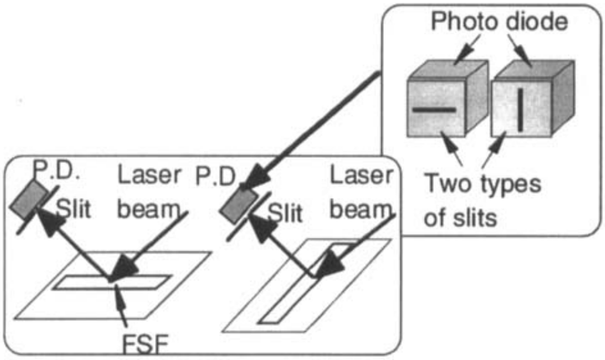


FIGURE.8 Setup for the observation of vibration mode

FIGURE.9 Illustration of film vibration

CONCLUSION

The conclusions of this study are summarized as follows. The vibration caused by FSF deformation consisted of fundamental and higher harmonic components. The vibration strength depended on the applied field, and fundamental and second-harmonic vibrations showed linear and quadratic behaviors to the electric field change, respectively. The second-harmonic component was induced from the contribution of soft mode. In the SmA phase of FLC, the vibration could be observed only in the thin film less than 200 layers, while in the SmC* phase the vibration strength was enhanced in the thicker film. The vibration mode of the reflected light was clarified.

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