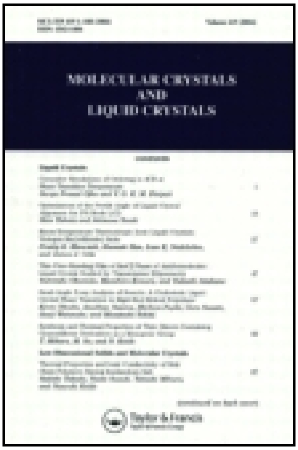

Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Vibration Analysis of Freely Suspended Liquid-Crystal Films

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Version of record first published: 18 Oct 2010

To cite this article: Kazuyuki Nakano, Masanori Ozaki & Katsumi Yoshino (2004): Vibration Analysis of Freely Suspended Liquid-Crystal Films, Molecular Crystals and Liquid Crystals, 412:1, 377-383

To link to this article: http://dx.doi.org/10.1080/15421400490440273

Mol. Cryst. Liq. Cryst., Vol. 412, pp. 377/[1987]–383/[1993], 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490440273

VIBRATION ANALYSIS OF FREELY SUSPENDED LIQUID-CRYSTAL FILMS

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We have studied the vibration analysis of freely suspended liquid-crystal films (FSFs) in the SmA phase by measuring reflected light from the surface of FSFs. Upon application of an electric field parallel to FSFs, the film vibration is generated. In SmA phase, molecule movement perpendicular to the electric field which are considered to be based on the electrically induced molecular tilt, which is a so-called electroclinic effect were observed. It is considered that the constriction of smectic layers by the electroclinic effect, contributes greatly to the film vibration.

Keywords: electroclinic effect; ferroelectric liquid crystal; freely suspended film; thin film; vibration

INTRODUCTION

The smectic liquid crystal has a layered structure and can be used in a freely suspended geometry whose thickness can be varied from two to several thousands of smectic layers. A freely suspended liquid crystal film (FSF) is not influenced by the binding potential of a substrate and provides unique possibility of studying the influence of reduced dimensionality on various physical properties of confined ordered liquids. In addition, it is sensitive to the external field and can be easily deformed upon application of external stress such as the acoustic vibration [1]. Application of electric field can induce mechanical vibration in the FSF. This phenomenon due to the coupling of the electric field and the mechanical stress is called the electromechanical effect. In previous studies on the electromechanical effect, a sandwich cell geometry consisting of two glass substrates was used

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[2]. In contrast, the FSF can easily change shape by application of a small electric field [3]. Therefore, it is optimal geometry for measurement of the electromechanical effect. In this paper, we report the detailed characteristics of the FSF vibration excited by the electric field.

EXPERIMENTAL

Figure 1 shows the molecular structures and the phase sequences of CS-1029 (Chisso), 4-n-octy1-4′-cyanobiphenyl (8CB) and 4-(1-methyl-heptyoxycarbonlyl-phenyl) 4′-octylbiphenyl-4-carboxylate (MHPOBC) used in this study. The FSF was prepared in a rectangular hole (5 mm × 10 mm) on a glass plate (30 mm × 30 mm) is smectic A (SmA) phase as shown in Figure 2(a). Subsequently the film was left undisturbed for several hours to obtain a uniform thickness of the film. The thickness of the film was determined by measuring the reflection spectrum of the film using photomultichannel analyzer (PMA-11, Hamamatsu) [4].

Figure 2(b) shows a schematic diagram of measurement of the FSF vibration. For excitation of the vibration modes the alternating voltage (1 kHz) was applied across the electrodes. The light source was a He-Ne

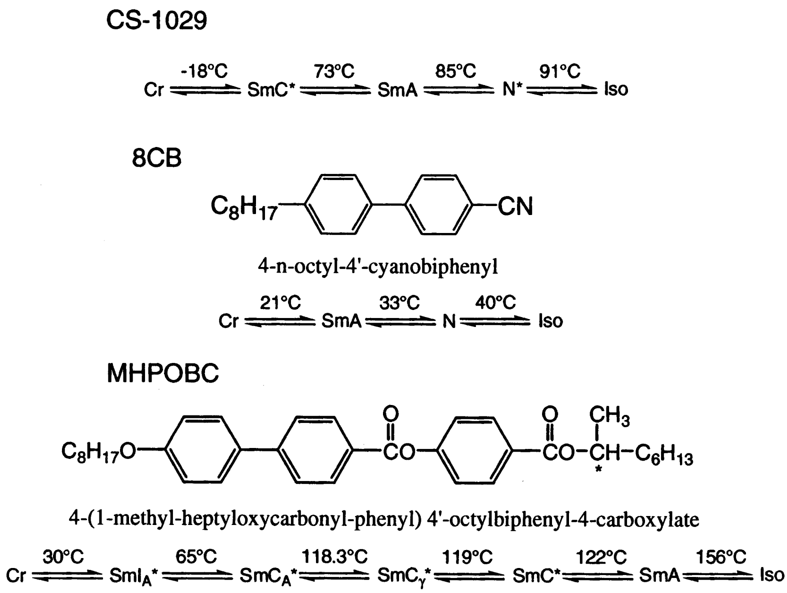

FIGURE 1 Molecular structures and phase sequences of smectic liquid crystals used in this study.

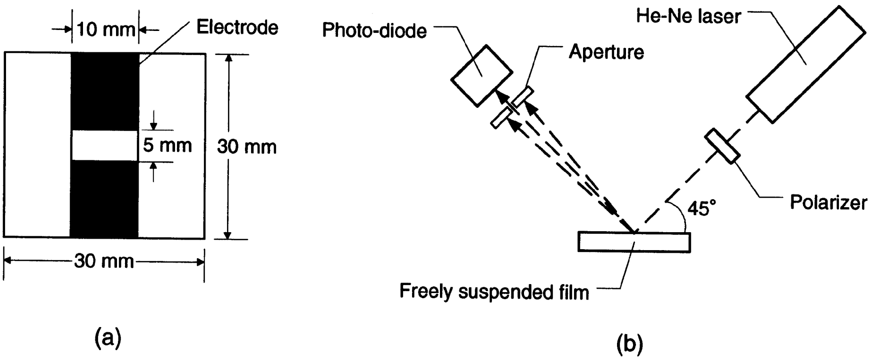

FIGURE 2 Schematic diagram of measurement of film vibration by an optical probe.

laser (632.8 nm). The laser beam was polarized parallel to the film surface (s-polarization) by a polarizer. The reflected laser beam from the FSF surface was detected by a photo-diode via an aperture used as a position-sensitive detector.

RESULTS AND DISCUSSION

Figure 3 shows the intensity change of the reflected light from the FSF surface of CS-1029 in the SmA phase in the reduced-aperture geometry. The second-harmonic response to the sinusoidal wave form of the applied voltage was observed.

In the reduced-aperature geometry, however, one can not the intensity change of the reflected light originates not only from deflection of the reflected light beam due to the film vibration but also from a reflectance change or scattering at the film surface [5]. In order to distinguish the contribution of the film vibration from that of the reflectance change and scattering, the optical response due to only a reflectance change and scattering was measured using an open-aperture geometry without aperture and these components were deducted from the intensity change of the reflected light in a reduced-aperture geometry. This procedure allows us to estimate only the contribution of the beam deflection due to the film vibration.

Figure 4 shows the optical response to the sinusoidal waveform of the applied voltage in the open-aperture geometry of MHPOBC in the SmA phase at s and p-polarization. When light with s-polarization was irradiated the intensity of the reflected light hardly changed as shown in Figure 4(b). This indicates that, for the light with s-polarization, neither reflectance

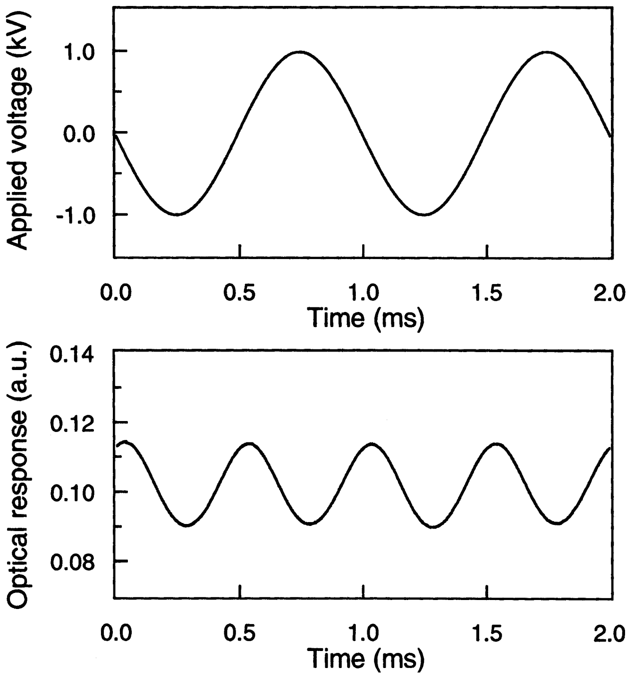

FIGURE 3 Intensity change of the reflected light on the FSF surface in SmA phase (75°C) of CS-1029. The film thickness is 247 layers.

change nor scattering contribute to the intensity change of the reflected light. Therefore, the optical response in the SmA phase shown in Figure 3 should originate from the beam deflection of the reflected light due to the film vibration.

Figure 4(c) shows optical response in the open-aperture geometry for the incident light with p-polarization. The reflective waveform which corresponds to twice the applied frequency was observed. Comparing Figure 4 (b) and (c), only light with p-polarization feels reflectance change on the film surface. In other words, the reflective index of the film for the p-polarization light changes upon application of the voltage, while that for the s-polarization remains unchanged ever upon the field.

This means that the molecules in the film move in the plane of the incident light which corresponds to that perpendicular to the electric field. Therefore, the optical response in the SmA phase might be associated with the electroclinic effect. In the SmA phase of FLC, the molecules tilt with respect to the layer normal upon the field application, which is the so-called electroclinic effect [6]. However, the field-induced molecular tilt is

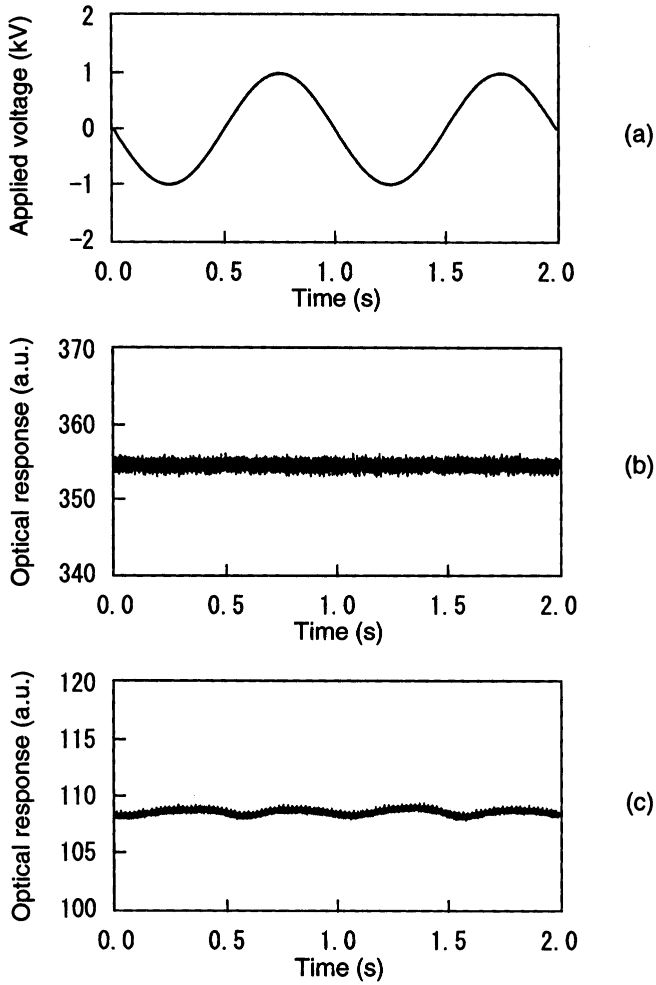

FIGURE 4 Optical response to the sinusoidal waveform of the applied voltage in an open-aperture geometry of MHPOBC in the SmA phase. ((a) applied voltage, (b) S-polarization, (c) P-polarization).

restricted to the plane perpendicular to the field, which coincides with the incident plane of the light in the geometry used in this study. Therefore, the reflective index for the s-polarization is not influenced by the field application and no reflectance change should be observed in the SmA phase.

Figure 5 shows the temperature dependence of the film vibration intensity in the SmA phase of CS-1029. As is evident from this figure, the film vibration intensity drastically increases near the phase transition from

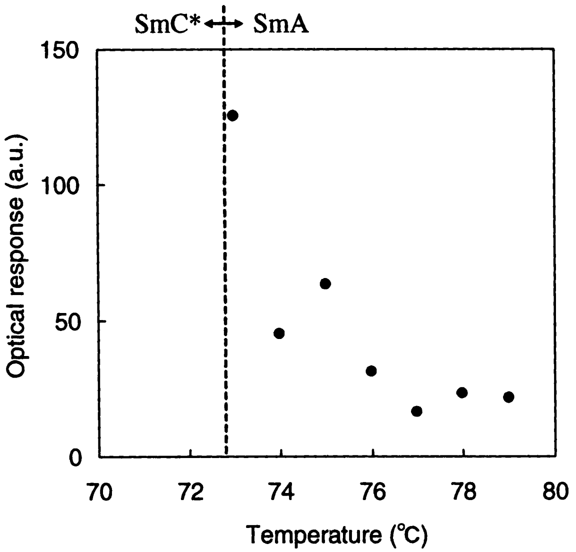

FIGURE 5 Temperature dependence of the film vibration intensity in SmA phase of CS-1029. The film thickness is 247 layers.

SmA phase to SmC* phase. This indicates the contribution of the electroclinic effect for the film vibration because the electrically induced molecular tilt has the pronounced maximum at the phase transition point from SmA phase to SmC* phase. The molecular tilt θ by the electroclinic effect is proportional to the externally electric field. The layer constriction induced the molecular tilt is proportional to $\cos\theta$, and it is proportional to the square of the externally electric field because $\theta \cong 0°$.

Contrary to a ferroelectric liquid crystal CS-1029, an achiral liquid crystal 8CB doesn't show the electroclinic effect. Figure 6 shows the intensity change in the reflected light from the FSF surface in SmA phase of 8CB in the reduced-aperture geometry. As is evident from this figure, the intensity change in the reflected light is negligible. This result indicates that the film vibration is not generated in SmA phase of the achiral liquid crystal molecules such as 8CB. In other words, the electroclinic effect contributes greatly to the film vibration in SmA phase.

CONCLUSIONS

We have carried out the vibration analysis of FSF in the SmA phase by measuring the electrooptical response of FSF. The molecules in the film move in the plane of the incident light which corresponds to that

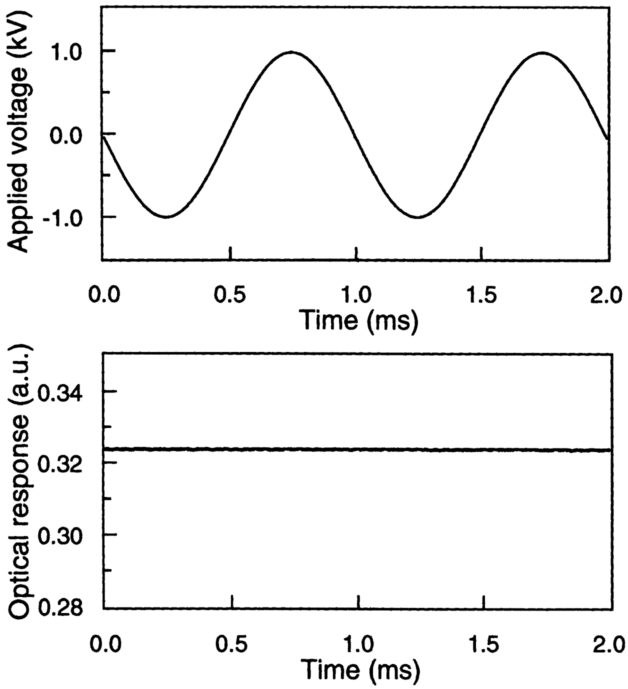

FIGURE 6 Intensity change of the reflected light on the FSF surface in SmA phase (25°C) of 8CB. The film thickness is 203 layers.

perpendicular to the electric field. The film vibration intensity drastically increases near the phase transition from SmA phase to SmC* phase. In addition, the intensity change of the reflected light is negligible small in SmA phase of the achiral molecules (8CB). These results also indicate the important contribution of the electroclinic effect for the film vibration.

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