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Citation	電気材料技術雑誌. 2001, 10(2), p. 169-172
Version Type	VoR
URL	https://hdl.handle.net/11094/81690
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電気材料技術雑誌　第10巻第２号
J. Soc. Elect. Mat. Eng.　Vol. 10, No. 2, 2001

Proceedings of ICEME 2001

Film Vibration Induced by Electric Field in Freely Suspended Films of Ferroelectric and Antiferroelectric Liquid Crystals

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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. The freely suspended film (FSF) is not influenced by any substrates and provides unique possibility to study the influence of reduced dimensionality on various physical properties of the confined ordered liquids. In addition, it 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] The application of the electric field can excite a mechanical vibration in FSFs. This phenomenon due to the coupling of the electric field and the mechanical stress is called electromechanical effect. In previous studies on the electromechanical effect in liquid crystals, a sandwich cell geometry consisting of two glass substrates was used.[2] In contrast, the FSF can be easily deformed by the small electric field.[3] Therefore, it is optimal geometry for the measurement of the electromechanical effect. In this study, we report the detailed characteristics of the FSF vibration excited by the electric field in the ferroelectric and antiferroelectric phases.

Smectic liquid crystal used in this study was 4-(1-methyl-heptyloxycarbonyl-phenyl) 4'-octylbiphenyl-4-carboxylate (MHPOBC). The FSF was prepared in a rectangular hole (2mm×10mm) on a glass plate (30mm×30mm) in the smectic A (SmA) phase. Subsequently the film was kept undisturbed for several hours to get a uniform thickness of the film. The thickness of the FSF was determined by measuring a reflection spectrum of the film in the SmA phase using Photo Multichannel Analyzer (PMA-11, HAMAMATSU). The scheme of the experimental setup is

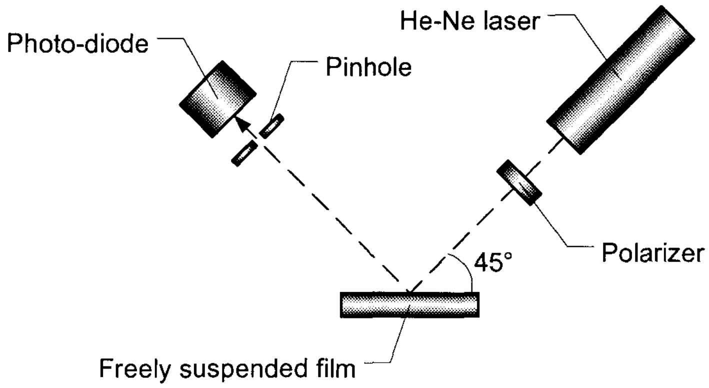


FIG. 1. Schematic diagram of the measurement of the film vibration by the reflected light.

presented in Fig. 1. For the excitation of the vibration modes the alternation voltage (1kHz) was applied across the electrodes. The light source is a He-Ne laser (632.8nm). The laser beam was polarized parallel to the film surface (s-polarization) by the polarizer. The reflected laser beam from the FSF surface is detected by a photo-diode via pinhole, used as a position-sensitive detector. In this configuration, the vibration spectrum should be observed as a second-harmonic component of the applied frequency because the light is symmetrically deflected with respect to the pinhole. The FFT spectra of the reflected light were measured by a digital phosphor oscilloscope (TDS3012, Tektronix) equipped with a FFT module.

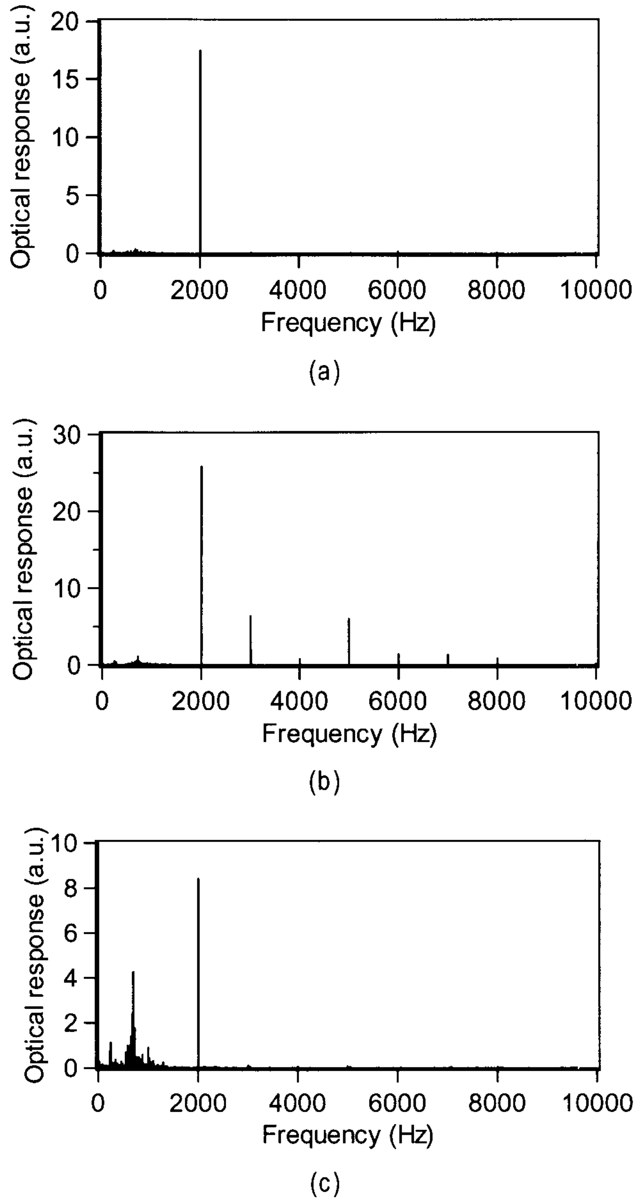


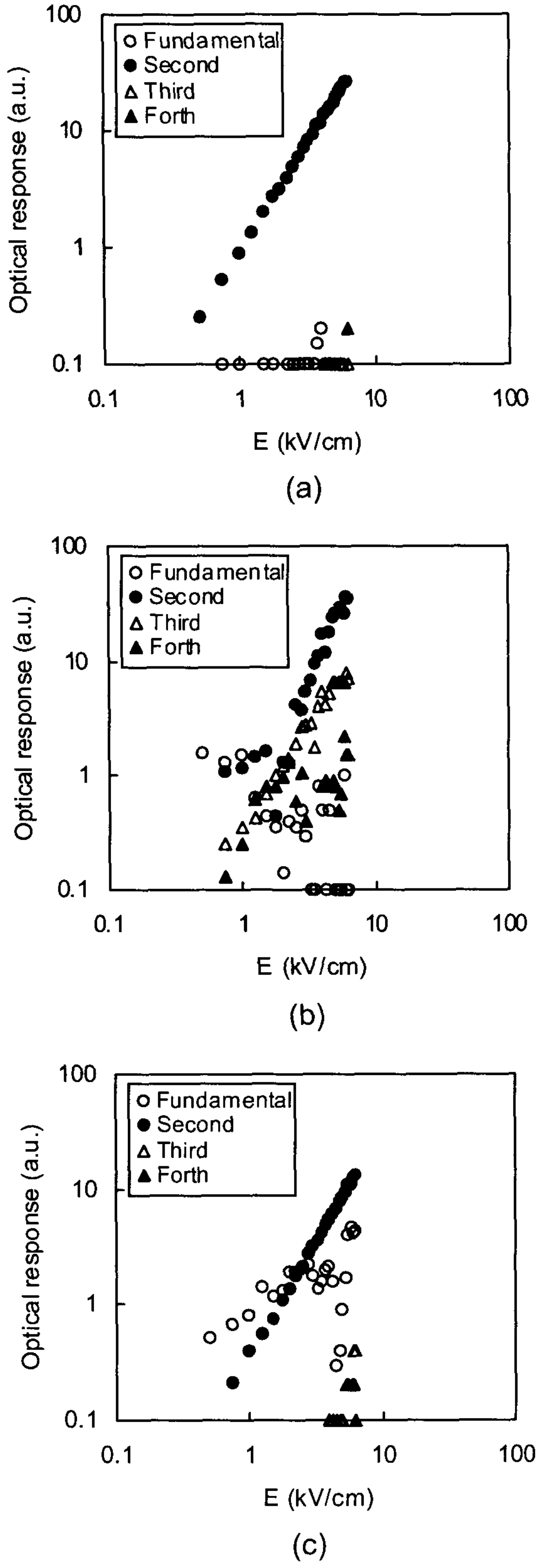
FIG. 2. FFT spectra of the reflected light intensity upon applying a sinusoidal voltage (1 kHz). ((a) SmA, (b) SmC*, (c) SmC$_A$*)

Figure 2 shows FFT spectra of the reflected light intensity upon applying a sinusoidal voltage of 1 kHz in frequency in the SmA (140°C), the SmC* (120°C) and the SmC$_A$* (100°C) phases. The film thickness is 45 layers. As is evident from the figure, the FFT spectra vary with the phases. Namely, in the SmA phase, only one signal was observed at 2kHz, which must correspond to a second-harmonic component of the applied voltage. On the contrary, in the SmC* phase, not only the second-harmonic but also higher order components of the signal appear in the spectrum. In the SmC$_A$* phase, fundamental and second-harmonic components are mainly observed, while higher order ones do not appear in the FFT spectrum.

Figure 3 shows the electric field dependence of the signal intensity of each component in the FFT spectra shown in Fig. 2. In the SmA phase, as seen from Fig. 3 (a), only the second-harmonic component is observed in the entire voltage range and its signal intensity is proportional to the square of the electric field E. On the other hand, in the SmC* phase, besides the second-harmonic component, the fundamental and other higher-order components are observed. In the SmC$_A$* phase, as shown in Fig. 3 (c), only fundamental and second-harmonic components are observed at low electric field. At higher field (>5 kV/cm), however, a third-harmonic component appears in the same manner as in the SmC* phase, as shown in Fig. 3 (c). It might be associated with a field-induced transition from the antiferroelectric to ferroelectric phases at about 5 kV/cm. From these results, it is found that higher other components were related to the molecular tilt and ferroelectricity.

Figures 4 (a) and (b) show the reflected light change in the geometry without the pinhole upon the polarity reversal of the applied voltage in the SmA and SmC* phases, respectively. In the SmA phase no optical response is observed, while in the SmC* phase the transient decrease in the reflected light can be observed. It is considered that this phenomenon was caused by the transient scattering mode (TSM).[4] At higher frequency such as 1kHz, the transient light scattering is not settled in the period of the polarity reversal of the field. Therefore, the intensity of the reflected light was complicatedly deformed from a sinusoidal waveform, which may be the cause of third or more harmonic components in the SmC* phase.

The conclusions of this study are summarized as follows. The vibration analysis of the FSF by measuring the reflected laser beam from a FSF surface was studied. The film vibration was generated by electric field and it was observed as a second-harmonic component of the FFT spectrum in the SmA phase. The intensity of the film vibration was proportional to square of electric field. In the SmC* phase, the FFT spectrum of the reflected light included not only second-harmonic but also fundamental and higher order components. These components might be attributed to the contribution of TSM.

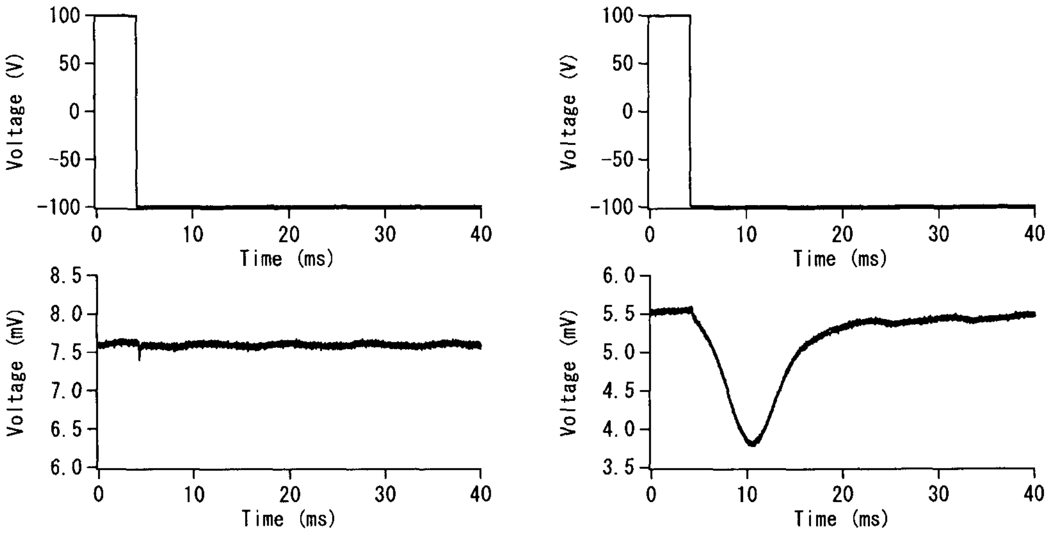


(a)

(b)

(c)

FIG. 3. Electric field dependence of the signal intensity of each component in the FFT spectra. ((a) SmA, (b) SmC*, (c) SmC$_A$*)



(a) (b)

FIG. 4. Reflected light change in the geometry without the pinhole upon the polarity reversal of the applied voltage. ((a) SmA, (b) SmC*)

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