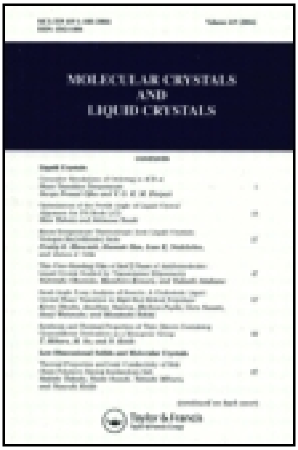

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AC Field and Frequency-Controlled Electrooptic Switching Using A Pyrimidine Type Ferroelectric Liquid Crystal†

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The physical contrast ratios (CRs) of an electrooptic switching element using a pyrimidine type ferroelectric liquid crystal (LC) was investigated. The electrooptic response of the element to the AC square wave voltages was shown to be strongly dependent both on the amplitudes and frequencies of the applied voltages. The CR showed a peak at V = 20 volts and at 500 Hz. This behavior was shown to be fairly well correlated to the voltage and frequency dependence of the apparent cone angle which was observed with a polarizing microscope.

The element made of this material showed a bistability depending on the surface treatments and the LC layer thickness. Almost all samples, which did not always have the bistability capability, showed that an AC electric field stabilized bistability even though all the tested LC materials have a small but positive dielectric anisotropy of about 0.2.

Keywords: ferroelectric liquid crystal, contrast ratio, bistability

INTRODUCTION

The electrooptic switch device using a surface-stabilized ferroelectric liquid crystal (SSFLC) was successfully demonstrated by Clark and Lagerwall.[1] Recently the AC electric field stabilized bistability (ACF-

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BS) with a chiral smectic LC having a negative dielectric anisotropy ($\Delta\epsilon < 0$) was reported by Pesant *et al.*[2], and Geary.[3] Meanwhile, Harada *et al.*[4] demonstrated a large area dot matrix display (with 640 × 400 pixels) whose major component was a pyrimidine type chiral smectic liquid crystal (LC) with a positive dielectric anisotropy.

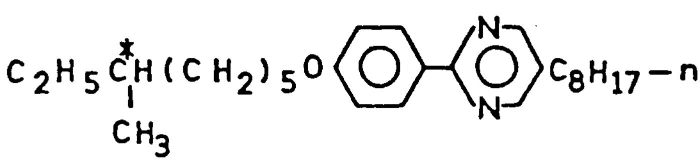
The basic operating mechanism of a multiplexed dot matrix display with ferroelectric LCs is completely different from those of twisted nematic or tunable birefringence types using ordinary nematic LCs. The latter are based on the response to the RMS values of the applied voltage which is characterized by an accumulative response to successive voltage pulses. On the other hand, the former does not show an accumulative response but a response to the applied waveforms with fidelity when the response time is short enough. In addition, the ferroelectric device does not show a threshold voltage inherent in the used LC material but the threshold is rather dependent both on the amplitude and width of the applied pulse voltages. However, in order to know the fundamental nature of the device, in this work, the electrooptic response of the device to the AC square wave voltages has been investigated. The material used in this work was mainly a chiral smectic LC containing pyrimidine ring, even though this single material is not always fit to realize a good surface-stabilized bistability, while a mixture with, e.g., MBRA does show a good bistability.[4]

The AC field stabilized bistability was shown to be observed for LC materials with a positive dielectric anisotropy.

EXPERIMENTAL

The material used in this work has the following name and molecular structure:

(S)-5-n-Octyl-2-[4′-(6″-methyloctyloxy)phenyl]pyrimidine



The surface treatment for molecular alignment was the ordinary rubbing applied to the polyimide or polyvinyalcohol coating. The typical thickness of the LC layers was about 2 μm.

The electrooptic response of the element was analyzed by detecting the transmitted light with a photomultiplier and by displaying the waveforms on an oscilloscope screen.

The apparent cone angle, which depends on the applied voltages, was measured with a polarizing microscope (Nikon OPTIPHOT-POL) equipped with a hot stage (Mettler FP82) for regulating the sample temperature. The textures appearing during the transition associated with the photoelectric switching were also monitored.

For comparison, other materials from E. Merck, supplied as scientific samples, were also measured.

RESULTS AND DISCUSSION

In Figure 1, the applied AC square voltage wave (lower trace) and the corresponding electrooptic response waveforms (upper trace) are shown. The definition of the contrast ratio (CR) is given as the ratio of the maximum and minimum levels of the transmitted light through the cell for a white light.

Figure 2 shows a plot of the CR versus RMS value of applied voltage (which is the same as the amplitude) where the frequencies are the parameters. At low frequency the CR increases with voltage, and it is followed by a saturation, then it tends to decrease; at middle fre-

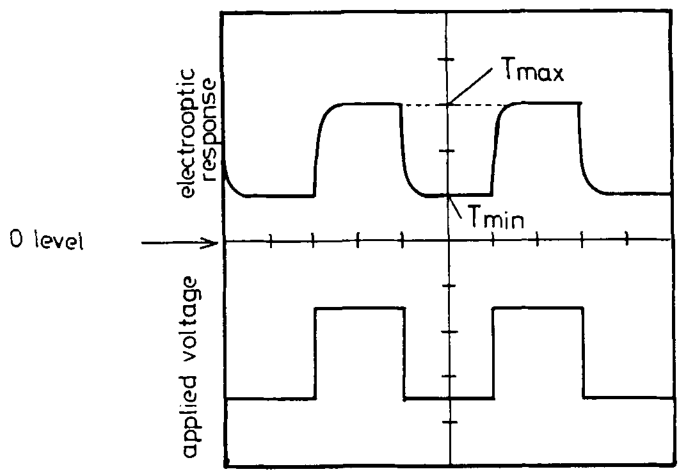


FIGURE 1 Sketch of applied AC square wave voltage form and that of corresponding electrooptic response of the element. T_{max} and T_{min} are the maximum and minimum values of the transmitted light, respectively. The contrast ratio (CR) is calculated as follows:

$$CR = T_{max}/T_{min}.$$

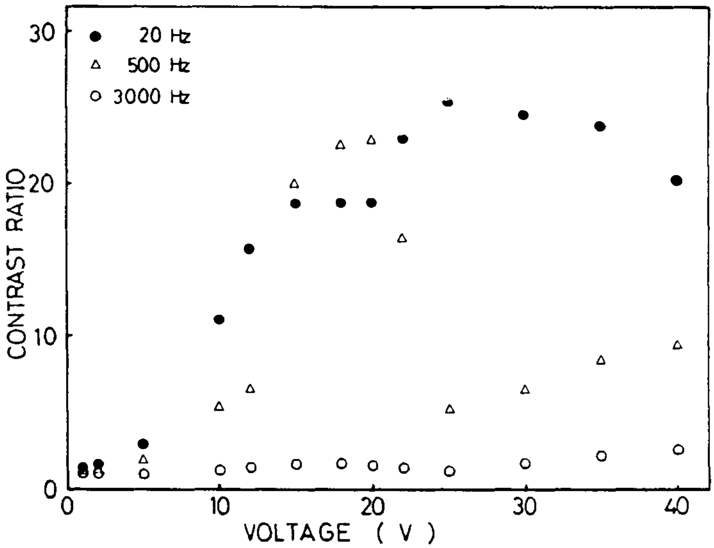


FIGURE 2 Voltage dependence of the contrast ratio for an element using the pyrimidine material. The parameters are frequencies.

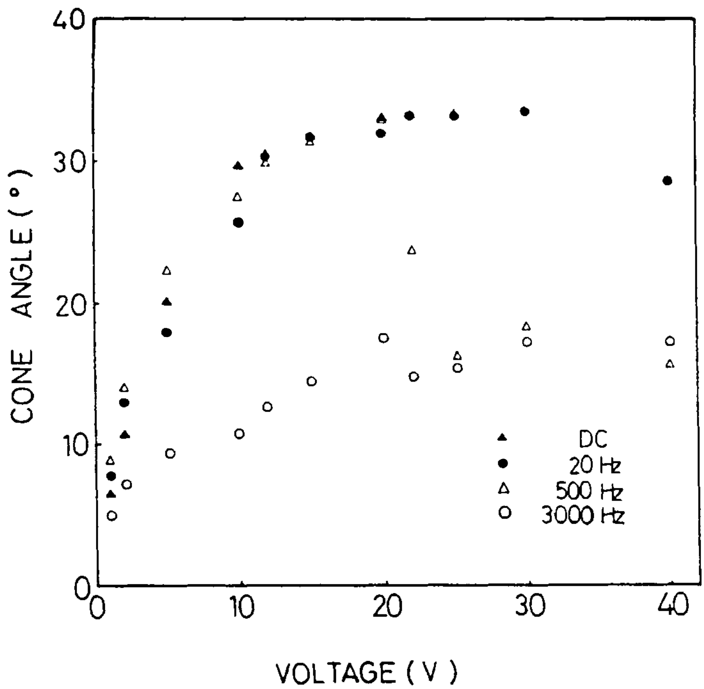


FIGURE 3 Voltage dependence of the cone angle (2θ) of the element using the pyrimidine material. The parameters are frequencies.

quency, say 500 Hz, the CR showed a peak reaching CR = 30 at 20 volts; on the other hand, at high frequency, at and over 3 kHz, no response is seen.

In order to know the origin of the variation of the CR with applied voltage and frequency, we examined the same variation of the cone angles with the voltage and frequency; as the CR is primarily altributed to the cone angle of the chiral smectic material, and it takes the maximum value when the cone angle is 45 degrees.

Figure 3 shows the result. The variation of the cone angle is almost the same as that of the CR. The decrease in the CR and cone angle at a higher voltage and high frequency may be attributed to an appearance of a slow responding part, whose duration is about 5 ms, appearing after a very fast responding wave front (about 300 μs), as shown in Figure 4. The appearance of the former was always seen when the applied voltage exceeds 22 volts. Because the slow responding part lasts for 5 ms, the response decreases when the frequency exceeds about 100 Hz. More detailed research on the variation of

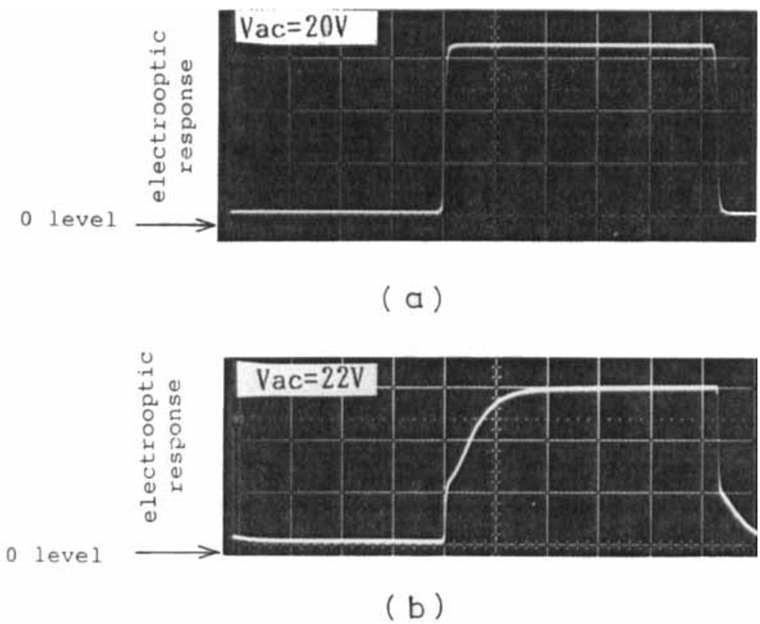


FIGURE 4 Oscillograms of the electrooptic response of the element using the pyrimidine material to the square wave voltages at 20 Hz. V_{ac} is the amplitude of the applied voltage; a) V_{ac} = 20 V, b) V_{ac} = 22 V, respectively. (X-axis: 5 ms/div, Y-axis: 0.1 V/div)

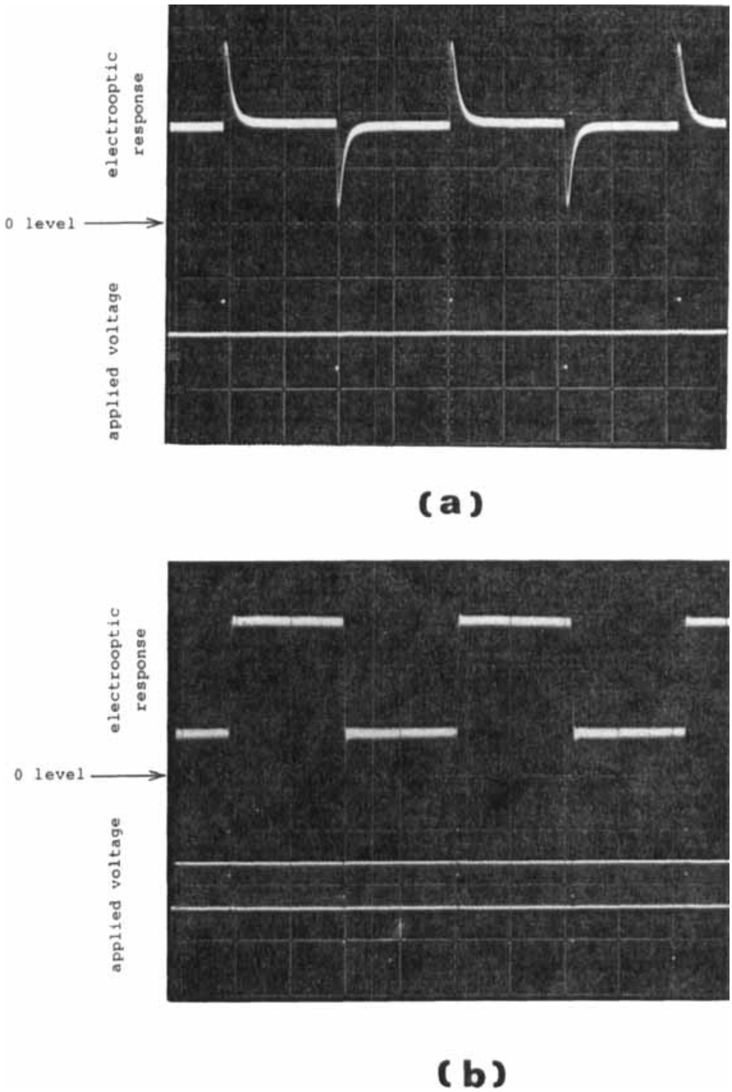


FIGURE 5 An example demonstrating AC field stabilized bistability (ACFS-BS) using pyrimidine material with a positive [X-axis: 5 ms/div, Y-axis: 10 mV/div (upper trace), 5 V/div (lower trace)]
(a) An electrooptic response to pulsed voltages (pulse width, τ = 100 μs, pulse height, V_0 = 30 V, and pulse interval, T = 10 ms), no ACFS-BS observed. (b) By superimposing an additional AC field (with amplitude voltage, V_{ac} = 22 V, and frequency, f = 100 kHz) the ACFS-BS is evidently recognized.

TABLE 1

AC field stabilized bistability

LC material	Cell thickness (μm)	Surface alignment	ACFS-BS
Pyrimidine	2.16	PI-PVA	◎
Pyrimidine	1.69	PI-PI	○
Pyrimidine	1.96	PI-MAP	△
ZLI-3232	1.45	PI-PI	◎
ZLI-3233	2.20	PI-PI	◎

◎; excellent ○ good △; medium
PI: Polyimide PVA: Polyvinylalcohol
MAP: N-Metyl-aminopropyltrimethoxy-silane

the cone angle with voltage and the appearance of a slow response at a higher voltage is needed.

Then we investigated the AC field-stabilized bistability (ACFS-BS); in Figure 5, the oscillograms show this effect. The cell made of the pyrimidine type LC, which does not have the surface-stabilized bistability (SS-BS), shows a striking ACFS-BS by applying an additional AC voltage field typically at $V_{ac} = 20$ volts at 100 kHz. Other material from Merck (ZLI-3232) having a positive $\Delta\epsilon$ [5] also showed the ACFS-BS. The material (Merck, ZLI-3233) with a negative $\Delta\epsilon$ [5] showed a striking ACFS-BS. All the results are tabulated and summarized in Table 1.

We investigated the $\Delta\epsilon$ of our pyrimidine compound by adopting the following two methods: one is to compare the dielectric permittivity of the homeotropically aligned smectic A phase, $\epsilon_{\parallel}$, and that of the isotropic phase, $\bar{\epsilon}$, then $\Delta\epsilon = 3/2(\epsilon_{\parallel} - \bar{\epsilon})$; another one is to measure directly the $\Delta\epsilon$ of an unwound smectic C* phase in terms of the surface effect in a very low electric field.

In figure 6, the result obtained by the former method is shown. The dielectric anisotropy $\Delta\epsilon$ is shown to be plus and is about 0.2 at 1 kHz, and tends to zero at high frequency, say 100 kHz. However, no inversion in the sign of $\Delta\epsilon$ occurred. The direct measurement of $\Delta\epsilon$ of the unwound smectic C* phase has also been conducted at very low AC voltage fields. From the obtained results the sign of $\Delta\epsilon$ seems positive qualitatively, but it is hard to obtain a quantitative data because effective (observed) values of $\Delta\epsilon$ is strongly dependent on the surface treatments and is influenced by the spontaneous polarization. A detailed investigation is now under way.

The occurrence of ACFS-BS in the material with a negative $\Delta\epsilon$

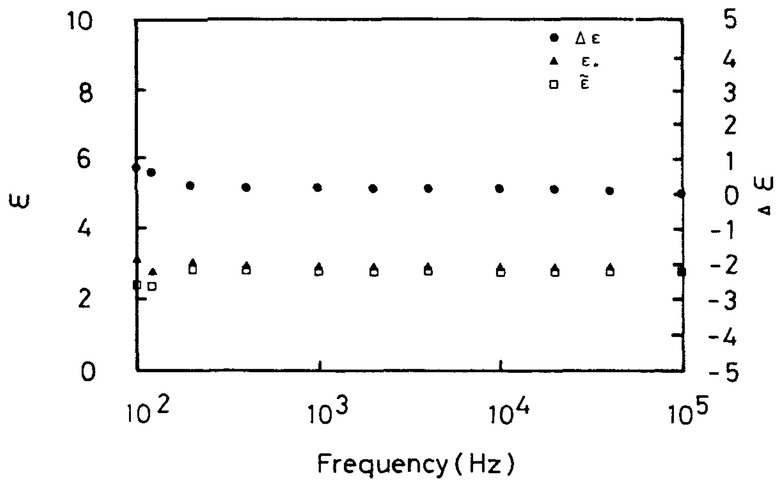


FIGURE 6 Dispersion of the dielectric constant of the pyrimidine material in calculating by $\Delta\epsilon = 3/2(\epsilon_{\parallel} - \bar{\epsilon})$ at the applied bias AC voltage, $V_b = 1$ V, measured with an LCR meter (YHP 4274A).

was also confirmed and it agrees with previous publications.[2,3] Through this work it was shown that the material that have a positive but a small $\Delta\epsilon$ also shows the ACFS-BS. The occurrence of this effect is thought to be caused by the flexoelectric effect. Measurement of the flexoelectric effect based on Prost and Pershan's method[6] is now under way.

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