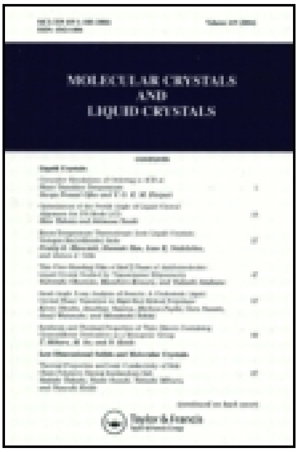

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Properties of Electro-Optic Cells with Chiral Dichroic Two-Frequency Liquid Crystals and Their Use for Thermal Mapping

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PROPERTIES OF ELECTRO-OPTIC CELLS WITH CHIRAL DICHROIC TWO-FREQUENCY LIQUID CRYSTALS AND THEIR USE FOR THERMAL MAPPING

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Abstract Experimental results obtained with the two-frequency driven guest-host electrooptic cells are described. Applicability of these cells as planary temperature indicators with critical temperature smoothly adjustable during measurements is discussed.

Keywords: electro-optic, liquid crystal cell, chiral, dichroic, thermal mapping

INTRODUCTION

Two-frequency driven LCD's have not found significant practical applications. The temperature dependence of the cross-over frequency that considerably limits the effective temperature range of the display[1], prevents their application. Their strong temperature dependence, however, enables to use such cells for measuring temperatures and to perform thermal mapping[2]. In particular, electrooptic guest-host cells without polarizers are suitable for this purpose. Colour or optical transmission of these cells change reversibly at a certain critical temperature T_c, the value of which depends on the driving frequency and amplitude. Thus the critical temperature of these indicators can be smoothly adjusted during measurements. The present paper describes experimental results obtained with two-frequency driven guest-host electrooptic cells satisfying the condition $0 < d/p < 4$ (where d is cell gap and p is cholesteric pitch).

EXPERIMENTAL

A conventional electrooptic cell with Mylar spacers was used. Homeotropic boundary conditions on ITO electrodes were achieved with lecithin layers (Lecithin from E.Merck). The cell gap was determined interferometrically and the pitch of the chiral structures was measured with the Cano-wedge method. The critical value of the cell gap d_c below which the chiral structure is spontaneously fully unwound between homeotropically orienting surfaces was also measured in the wedge cell.[3,4]

The basic parameters of the nematic host mixtures are listed in Table I. All mixtures contained 1.2 wt.% of the red dichroic dye D2 (BDH Limited). The required pitch was adjusted by dissolving cholesteryl nonanoate (CN).

TABLE I Physical data for 2F-nematic mixtures

Mixture	t_i (°C)	f_c (kHz)	$\Delta\varepsilon_H$	$\Delta\varepsilon_L$	Δn	q (Hz/°C)
ZLI 2979	126	2.0	-1.2	+1.9	0.12	350
ROCHE 3333	68	3.2	-4.7	+4.1	0.1	990
ROCHE 3421	81	0.4	-4.7	+5.7	0.1	88

t_i- clearing point, $\Delta\varepsilon_{L,H}$- dielectric anisotropy in low and high frequency range, f_c - cross-over frequency Δn- birefrigence, $q = \Delta f_c/\Delta t$ for temperature range from 0 °C to 40 °C.

A polarizing microscope and an optical bench equipped with a heating/cooling stage and a photocell were used for the experiments. The electrooptic measurements were performed in transmission using unpolarized white or monochromatic light (λ = 465 nm) and square-wave driving voltages. A digital storage oscilloscope (Tektronix 5110 with Waveform Digitizer 5D10) and a XY plotter were used for recording the static and dynamic characteristics.

RESULTS AND DISCUSSION

The optical transmission of the two-frequency driven electrooptic cells depends on frequency, voltage, and temperature. Typical results are presented in Figure 1.

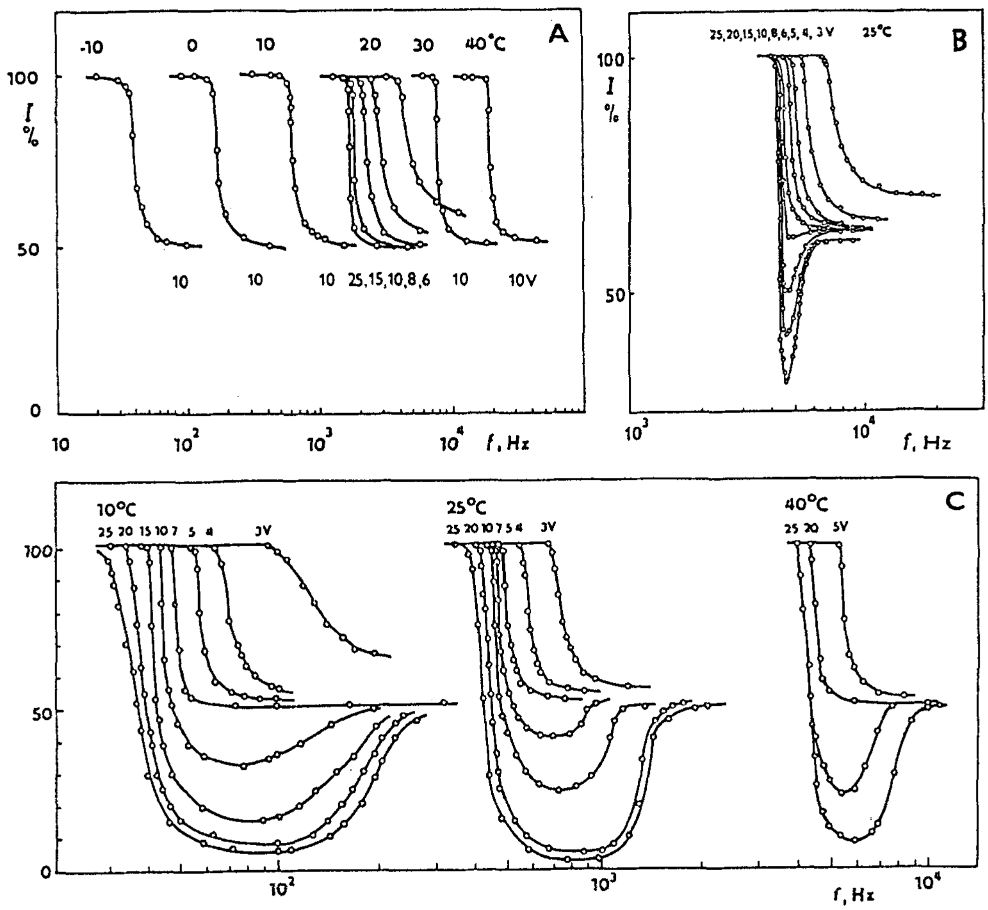


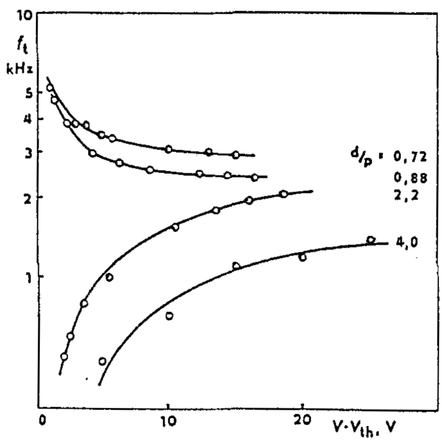
FIGURE 1 Frequency dependencies of monochromatic light transmission (λ = 465 nm) through the electro-optic cells containing different nematic mixtures with 1.2 wt.% dichroic dye D2 at various temperatures and driving voltages.
A) ZLI 2979 B) ROCHE 3333 C) ROCHE 3421

where two kinds of frequency functions can be observed:

(i) Dependence without a minimum which is characteristic for electrooptic changes induced by an electric field only, and

(ii) Dependence in which the optical transmission passes through a minimum. The observed minima are caused by electrohydrodynamic effects which are suppressed at sufficiently high frequencies.

A threshold frequency, f_t, can be defined as the frequency needed to change the transmittance from 100% to 10%. Typical voltage dependencies of f_t are shown in Fig. 2. It can be seen that two different kinds of



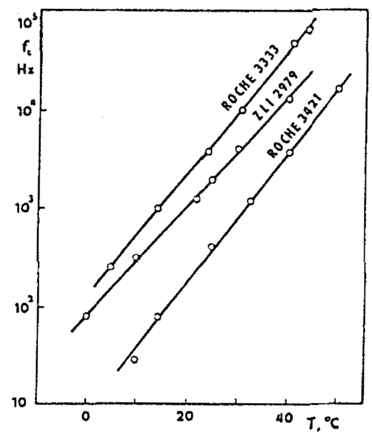


FIGURE 2 Voltage dependences of threshold frequency for chiralized nematic mixture ZLI 2979 with various values of the d/p ratio at 25 °C.

FIGURE 3 Temperature dependences of extrapolated cross-over frequencies for different 2F-nematic mixtures.

f_t voltage dependences exist according to the value of the d/p ratio:

1) If $d/p < d_c/p$ then f_t decreases with increasing voltage and the relationship between V and f_t is given by

$$\log f_t = k/(V - V_{th}) + \log f'_c \qquad (1)$$

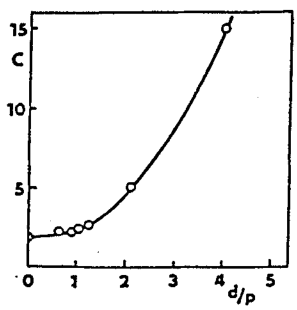
where k is a constant, V_{th} is the threshold voltage at $f \gg f_c$ and f'_c represents the frequency approaching the cross-over frequency, mainly in the cells with the gap around the critical value d_c.

2) In the case $d/p > d_c/p$ the f_t increases with increasing voltage as the threshold voltage for untwisting

the cholesteric helix increases with decreasing pitch.

The temperature dependences of the frequencies f'_c are shown in Fig. 3. These plots are linear with high slopes ($q = \Delta f/\Delta T$). The average slope values between 0 °C and 40 °C are summarized in Table I for three investigated mixtures. High values of q are very suitable for realizing 2F-electrooptic temperature indicators. Specifically, the maximum q value of approximately 5 kHz/K at temperatures about 40 °C was determined for the mixture Roche 3333.

A contrast, C, was defined as the T_{max}/T_{min} ratio, where T_{max} is the maximum transmission of monochromatic light (λ = 465 nm), and T_{min} is the transmission of the cell for the $f \gg f_c$. This value is very low (approx. 2) in the cells containing nematic mixtures, however it increases with increasing d/p ratio (Fig. 4) Unfortunately, if the d/p ratio exceeds some critical value $(d/p)_c = K_{33}/2K_{22}$ (where K_{ii} are the elastic constants for bend and twist) the threshold voltage strongly increases (Fig. 5)



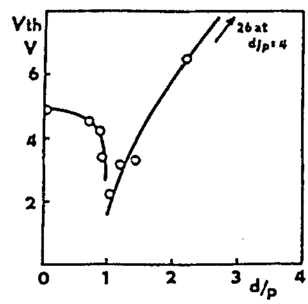


FIGURE 4 Contrast as a function of the d/p ratio. Mixture ZLI 2979 at 25 °C.

FIGURE 5 Threshold voltage as a function of the d/p ratio. Mixture ZLI 2979 at 25 °C.

and the frequency dependence of the optical transmission adopts step-like character at low voltage if d/p > 1 (Fig. 6). In the first step a strain or finger-print texture arises which changes with the increasing frequency to the planar cholesteric texture.

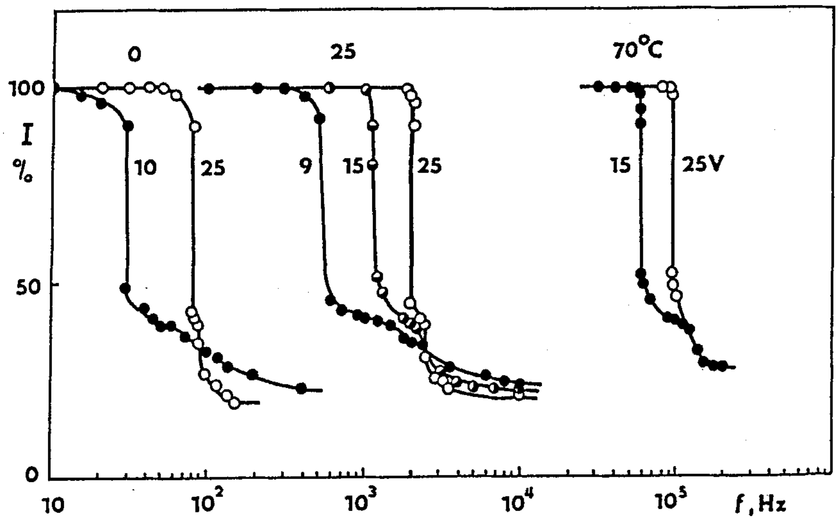


FIGURE 6 Frequency dependences of monochromatic light transmission (λ = 465 nm) through the electro-optic cells containing chiralized nematic mixture ZLI 2979 at various temperatures and driving voltages. (d/p = 2.2 at d = 10.4 μm)

Temperature dependences of the optical transmittance are crucial for the present purpose. Two typical kinds of these dependences are shown in the Figures 7 and 8. If the d/p ratio is lower than some critical value the optical transmission of the 2F-cell changes within some narrow temperature interval. The interval shifts to higher temperatures with increasing voltage and frequency, and its width decreases with increasing voltage (Fig. 7). The problem of low contrast can be solved by using mixtures which exhibit pronounced electrohydrodynamic effects (Fig. 9 B). By doping them with organic ions, electrohydrodynamic effects can be induced at $f > f_c$.

In case $d > d_c$ the contrast is higher and the dependences of the optical transmission have a step-like character (Fig. 8). Therefore two temperature levels can be distinguished by means of such cells (Fig. 9 C). However, some problems with hysteresis effects must still

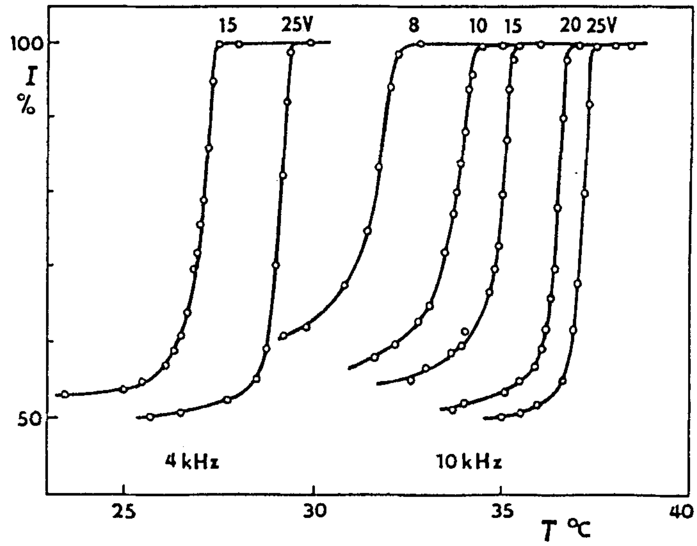


FIGURE 7 Temperature dependences of an optical transmission of the two-frequency driven electro-optic cell at various frequencies and voltages: Nematic mixture ZLI 2979 (d/p = 0)

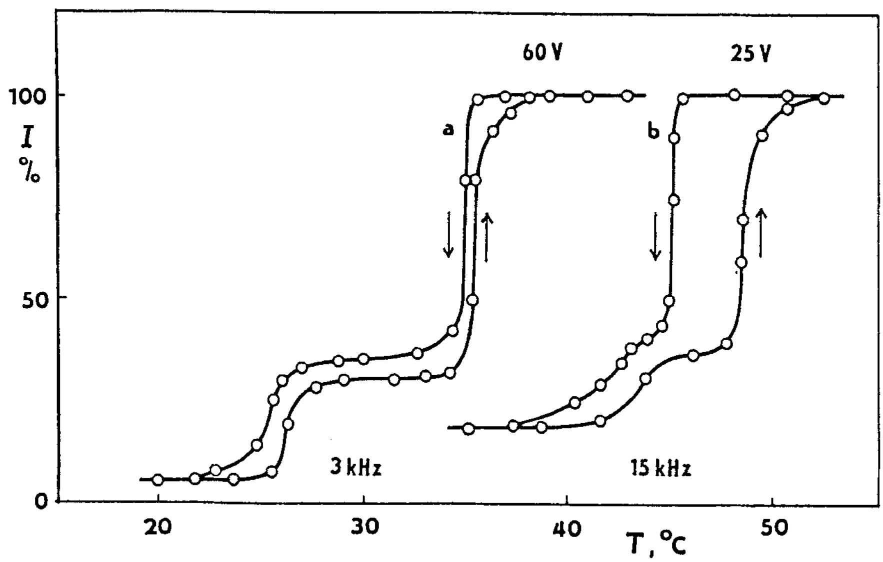


FIGURE 8 Temperature dependences of an optical transmission of the two-frequency driven electro-optic cell at various frequencies and voltages: Chiralized nematic mixture ZLI 2979 a) d/p = 2.2 b) d/p = 4.0

be solved and a rise of the threshold voltage should also be considered.

Realization possibilities of film-like 2F-electro-optic temperature indicators seems also to be very interesting. PDLC or NCAP films of this type would have been useful for some purposes in the field of thermal mapping.

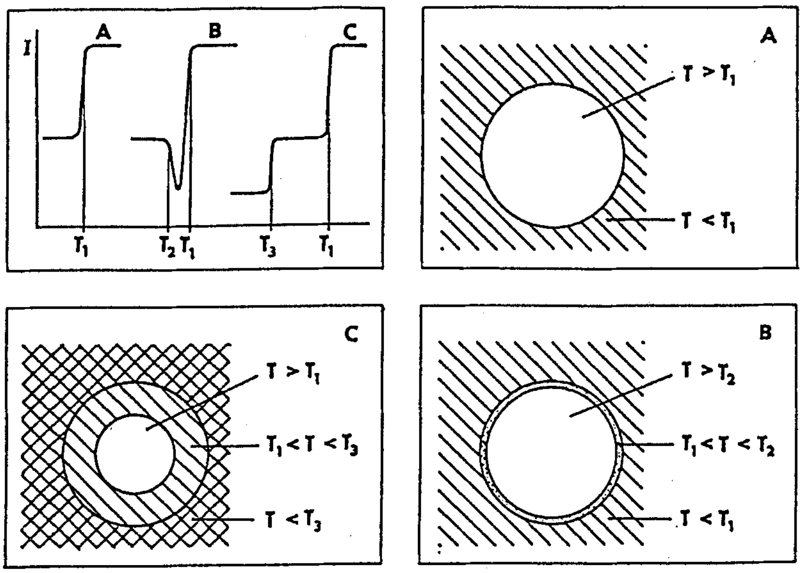


FIGURE 9 Schematic of thermal field visualization with different two-frequency driven electro-optic cells:

A) $d < d_c$ cell with only field effect

B) $d < d_c$ cell with partial electrohydrodynamic effect

C) $d > d_c$ cell with phase change field effect

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