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A NOVEL ELECTRO-OPTIC STORAGE MODE IN SMECTIC A LIQUID CRYSTALS

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Résumé. — Un nouvel effet mémoire dans les smectiques A est décrit et quelques-unes de ses propriétés sont étudiées.

Abstract. — A new electro-optic storage mode in smectic A liquid crystals is described and some of its characteristic features are given.

1. Introduction. — Recently, it has been shown that a destabilizing electric or magnetic field operating on monodomain samples of smectic A liquid crystals could induce distortions which, in turn, generate defects [1, 2].

Let us consider a planar sample of a smectic A, the dielectric anisotropy (ϵ_a) of which is positive, submitted to an increasing electric field. As long as the applied voltage V is less than a threshold value V_{th} , the orientation of the molecules remains unchanged; then, when $V = V_{th}$, two periodic arrays of defects appear. With still increasing voltage, the following phenomena are successively observed: the regular arrays of lines change into focal conics (Fig. 1) [3]. The size of these focal conics decreases when V increases until a completely scattering texture is observed. Then this texture gradually fades until, for $V = V_{th}$ the molecules have tilted by an angle of 90° and the typical conoscopic pattern of an homeotropic sample is observed.

Two storage modes can be obtained:

- i) the scattering domains remain stable in time, when the field is removed: first storage mode;
- ii) if the field is cancelled after the sample has

FIG. 1. — Scattering texture obtained by applying a voltage of 25 $V_{r.m.s.}$ ($f = 1$ kHz) on a 22 μm thick K 24 sample
($T_{SN} - T = 0.5^\circ C$).

become homeotropic, another scattering texture appears, which is stable in time too: this is the second storage mode.

The following diagram summarizes the above described effects:

In this paper, we present some measurements of the characteristic features of the first storage mode.

2. Experimental details. — The measurements have been performed on two biphenyl compounds : 4 cyano-4'-n-octyloxybiphenyl (M 24)

$$\epsilon_a = 8.5 \text{ at } 66\text{ }^{\circ}\text{C}$$

and 4 cyano-4'-n-octylbiphenyl (K24)

$$\epsilon_a = 7.5 \text{ at } 31\text{ }^{\circ}\text{C}.$$

The sample, sandwiched between two nesa coated glass plates, separated by 12-290 μm Mylar spacers, is placed into an electronically regulated oven, and its temperature is measured with an accuracy of 0.1 $^{\circ}\text{C}$. The planar anchoring is obtained by evaporating silicon monoxide under oblique incidence. A function generator IEC F34 supplies a sine-shaped voltage pulse the duration of which can be varied ; the frequency ranges from 0 to 100 kHz.

The sample is observed through a polarizing microscope and its transmission level between parallel polarizers is recorded through a photocell on a storage oscilloscope. Figure 2 gives the block-diagram of the experimental set-up.

FIG. 2. — Block diagram of the experimental set-up.

3. Experimental results. — We have studied the threshold voltage V_{th} versus frequency f , temperature T and sample thickness in the following ranges : $0 < f < 100\text{ kHz}$, $12\text{ }\mu\text{m} < d < 75\text{ }\mu\text{m}$, $0.2\text{ }^{\circ}\text{C} < T_{SN} - T < 10\text{ }^{\circ}\text{C}$ (T_{SN} is the smectic A-nematic transition temperature). As shown on figure 3, V_{th} is best fitted by the law : $V_{th} = Ad^{1/2}(T_{SN} - T)^{1/3}$; the value of A depends on the studied compound ⁽¹⁾.

(1) The law $V_{th} = Ad^{1/2}(T_{SN} - T)^{1/3}$ has been checked up for thicknesses up to 290 μm but for this thickness, our apparatus has restricted us to $T_{SN} - T < 3\text{ }^{\circ}\text{C}$.

FIG. 3. — Threshold voltage V_{th} as a function of the thickness d of the sample and the difference $T_{SN} - T$ (T_{SN} is the smectic A-nematic transition temperature) in K 24 : $+$ $d = 75\text{ }\mu\text{m}$, $\bullet$ $d = 50\text{ }\mu\text{m}$, $\square$ $d = 22\text{ }\mu\text{m}$, $\times$ $d = 12\text{ }\mu\text{m}$, $V_{th} = Ad^{1/2}(T_{SN} - T)^{1/3}$ with $A = 4.5\text{ V} \cdot \mu\text{m}^{-1/2} \cdot ^{\circ}\text{C}^{-1/3}$.

Figure 4 displays oscillograms of a K 24 sample (thickness 12 μm , $T_{SN} - T = 0.5\text{ }^{\circ}\text{C}$) submitted to a 150 V pulse of variable length. The upper curve is the photocurrent versus time and the lower curve the voltage applied to the sample versus time. For $\tau = 7\text{ ms}$, the sample experiences the successive states described in the preceding section : initial planar structure (clear), arrays of lines moving into a scattering texture (black) then homeotropic structure (clear) which relaxes into the second scattering structure (black) when the voltage is removed. For $\tau = 3\text{ ms}$, the structure obtained is only slightly scattering, the highest contrast ratio is then not reached. For $\tau \geq 4\text{ ms}$, the highest contrast ratio is achieved, provided either by the first scattering texture or the second one ; but for $\tau = 4\text{ ms}$ the sample is frozen in the first scattering texture and the revelation time is then the shortest. So a critical pulse length τ_c exists, for which the highest contrast is achieved in the shortest time. On figure 5 τ_c is plotted as a function of V/V_{th} for two values of d . Typically, for $d = 12\text{ }\mu\text{m}$, the critical pulse length, which is 60 ms at 80 V ($V/V_{th} = 5.7$), is reduced down to 7 ms at 140 V ($V/V_{th} = 10$) for $T_{SN} - T = 0.8\text{ }^{\circ}\text{C}$. The variation of τ_c with V/V_{th} is roughly fitted by a law

FIG. 4. — Oscillograms of a K 24 sample ($d = 12 \mu\text{m}$, $T_{\text{SN}} - T = 0.5^\circ\text{C}$). The upper curve is the light transmitted by the sample between parallel polarizers versus time when it is submitted to a 150 V pulse of variable duration (lower curve).

FIG. 5. — Critical pulse length τ_c versus V/V_{th} for two K 24 samples : $\bullet$ $d = 12 \mu\text{m}$, $T_{\text{SN}} - T = 0.8^\circ\text{C}$; $+$ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 0.25^\circ\text{C}$; $*$ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 0.5^\circ\text{C}$; Δ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 1^\circ\text{C}$. The frequency of the applied field is 1 kHz.

FIG. 6. — Reciprocal of the critical pulse τ_c versus $(V/V_{\text{th}} - 1)^3$ in K 24 samples : $\bullet$ $d = 12 \mu\text{m}$, $T_{\text{SN}} - T = 0.8^\circ\text{C}$; $+$ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 0.25^\circ\text{C}$; $*$ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 0.5^\circ\text{C}$; Δ $d = 22 \mu\text{m}$, $T_{\text{SN}} - T = 1^\circ\text{C}$.

$(V/V_{\text{th}} - 1)^{-3}$ (Fig. 6). At fixed V/V_{th} , τ_c increases with sample thickness.

The lifetime of the storage mode depends both on sample thickness and temperature :

$T_{\text{SN}} - T^\circ\text{C}$	0.25	0.5	0.75
lifetime (22 μm)	20 s	15 min.	> 60 h
lifetime (12 μm)	15 s	7 min.	> 60 h

4. Applications and conclusion. — This storage mode could be used for projection of written slides on a large

FIG. 7. — Image of a scattering texture, with grey tones, against a planar structure projected on a large screen. K 24 sample $d = 20 \mu\text{m}$, $T_{\text{SN}} - T = 0.5^\circ\text{C}$.

screen, the slide being, of course, a sample of smectic A submitted to an electric field. Two parameters, thus, become important : the resolution and the contrast ratio. The resolution is mainly determined by the size of scattering domains which is imposed by the temperature and the sample thickness : typically at a temperature 0.5°C below T_{SN} , in a $22\text{ }\mu\text{m}$ thick sample, the resolution is $20\text{ }\mu\text{m}$.

The contrast ratio was determined by projecting the image of a cell on a screen and by measuring the intensity with a luxmeter (Fig. 7). The ratio between the light

transmitted by the planar structure and the light transmitted by the scattering structure is higher than $40:1$. Grey tones can be obtained with gradual applied voltages.

Once the scattering texture is obtained, the initial planar alignment can be restored by heating the sample up to the nematic phase, and then cooling it down to the smectic phase at a rate moderate enough to avoid the thermo-optic effect [4].

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