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L. Tsonev[a]; M. Petrov[a]
[a] Institute of Solid State Physics, Bulgarian Academy of Sciences, 72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria,

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Scanning of the surface polar angle values in liquid crystal cells using the surface memory effect

L. TSONEV* and M. PETROV
Institute of Solid State Physics, Bulgarian Academy of Sciences,
72 Tzarigradsko Chaussee Blvd., 1784 Sofia, Bulgaria

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An optical polarization method for indication of recorded oriented smectic C textures by the process of surface memorization and their accumulation and storage in the nematic temperature range is presented. The recorded accumulated data are identified with the surface conditions—the polar and azimuthal angles. Using strong boundary conditions the assumption is made that the interval for recorded and accumulated textures increases when the anchoring energy is weak.

1. Introduction

The effect of memorization of an oriented smectic texture in the temperature range of the nematic phase has been studied by many authors [1, 2], but the possibility that this phenomenon be considered as a line of application has not been presented till now. Recently we demonstrated [3] that by scanning the recording time t_{rec} in the SmC state we can accumulate and memorize a set of oriented smectic C textures. We like to name this process 'multipages' expressing in this way the accumulation of a set of textures, each of them considered as a 'page', where some information is written and memorized. These textures are stored in the nematic phase (upon heating) and can be distinguished by optical microtextural analysis. The erasure of the accumulated pictures is realized by selectively removing each of the textures by varying the erasure time. This phenomenon was presented [3] as various oriented textures which are difficult to separate by simple microtextural analysis, although it is possible to note the successive accumulation or erasure (removal) of some elements of the different textures. The purpose of the present communication is to develop a method giving us the possibility of distinguishing and detecting more objectively and sharply the accumulated and erased pictures, as well as of analysing the information contained in them. We like to identify the information with real physical parameters such as surface conditions—the polar (θ) and azimuthal (φ) angles of the surface director $\mathbf{n}_s$.

2. Experimental results and discussion

We standardized our cells to ensure optimum conditions for surface memorization and to reduce the parameters which may be varied during the entire experimental procedure. We used only OOBA as the liquid crystal substance, only glass plates covered with ITO and then rubbed on filter paper (generating the easy direction $\mathbf{n}_o$) as the cell walls and only $d = 20\,\mu\text{m}$ thick cells. The cells were filled with OOBA in the isotropic state (160°C) by capillary flow.

The recording and erasure processes are described in detail in [3]. We examined the cells by polarization microscopy (polarizer P, analyser A), measuring the intensity I^{tr} of the transmitted light (mean wavelength $\lambda = 0.5\,\mu\text{m}$) by means of a photodiode (detected area $2\,\text{mm}^2$) in various optical configurations (i.e. of the mutual orientations of P, A and $\mathbf{n}_o$). The intensity is evaluated in arbitrary units; $I^{\text{tr}} = 0$ means that no light is reaching the detector at all, and normalization procedures are related to the maximum intensity I_o^{tr}, corresponding to the experimental situation being considered. An example of a recorded, partially and fully erased texture is given in figures 1 (*a*, *b*, *c*), respectively.

The intensity values are related to the averaged effective birefringence $\langle \Delta n_{\text{eff}} \rangle$ by the formula [4]:

$$I^{\text{tr}} = I_o^{\text{tr}} G(\chi, \gamma) \sin^2(\delta/2) \qquad (1)$$

where

$$G(\chi, \gamma) = \cos^2 \chi - \sin^2(2\gamma) \sin 2(\gamma - \chi) \qquad (2)$$

$$\delta = (2\pi d/\lambda)\langle \Delta n_{\text{eff}} \rangle \qquad (3)$$

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*Author for correspondence; e-mail: lyubo@issp.bas.bg

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(*a*) (*b*) (*c*)

Figure 1. Successive photographs of a single memorized smectic C texture taken during the erasure process in the nematic phase: (*a*, *b*, *c*).

and

$$\chi = (\mathrm{P}\wedge\mathrm{A}), \quad \gamma = (\mathbf{n}_o\wedge\mathrm{P}).$$

The parameter Δn_{eff}, in turn, is defined by the equations:

$$\Delta n_{\mathrm{eff}} = n_{\mathrm{eff}} - n_o \tag{4}$$

$$n_{\mathrm{eff}}^{-2} = \sin^2\theta\, n_e^{-2} + \cos^2\theta\, n_o^{-2} \tag{5}$$

and n_e, n_o are the main extraordinary and ordinary indices of refraction of the liquid crystal in the nematic (uniaxial) state. The latter quantities obey the following relations: $n_e - n_o = \Delta n$, $\varepsilon_e - \varepsilon_o = \Delta\varepsilon$, $\varepsilon = n^2$, where ε_e is the extraordinary and ε_o is the ordinary dielectric permittivity; therefore $\Delta\varepsilon \approx 2n_o\Delta n$, i.e. $\Delta n \approx \Delta\varepsilon/2n_o$; and from the literature we have [5] $n_o = 1.50$, $\Delta\varepsilon = 0.018$.

We can summarize the meaning of the above formulae as follows: the measured transmitted intensity variations can be converted into variations of $\langle \Delta n_{\mathrm{eff}} \rangle$—by equations (1), (2) and (3); and then into variations of the effective averaged polar angle θ—by equations (4) and (5).

We carried out the measurements for three optical configurations:

(a) $\mathrm{A} \perp \mathrm{P}$, $\mathbf{n}_o \perp \mathrm{P}$ (where $G = 0$);
(b) $(\mathrm{A}\wedge\mathrm{P}) = 45°$, $\mathbf{n}_o \perp \mathrm{P}$ (where $G = 1/2$);
(c) $\mathrm{A} \perp \mathrm{P}$, $(\mathbf{n}_o\wedge\mathrm{P}) = 45°$ (where $G = 1$).

Configuration (c) must be preferred due to the optimum observation conditions.

The experimental results are presented in figures 2 and 3 and in tables 1 and 2.

We used the intensity of the transmitted linearly polarized light to detect and distinguish the set of recorded oriented pictures. The first feature which one can note is that the level of the transmitted light in the smectic C state obtained by scanning the recording time

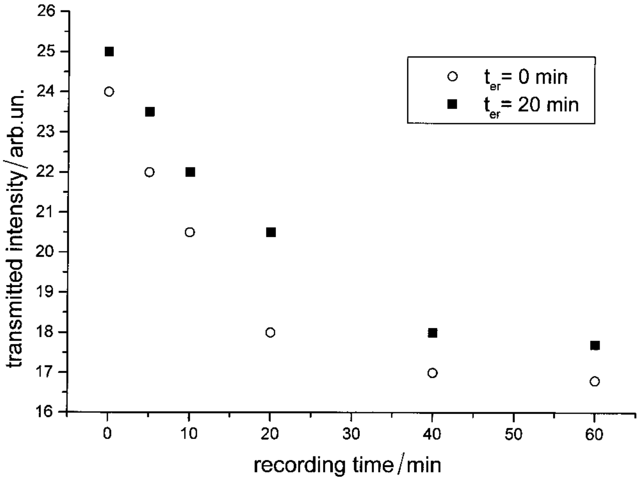

Figure 2. Transmitted light intensity versus recording time for several fixed erasure time values.

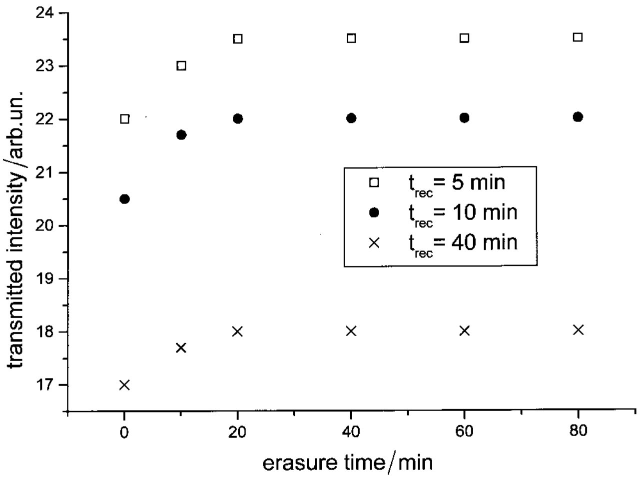

Figure 3. Transmitted light intensity versus erasure time for several fixed recording time values.

Table 1. Averaged effective birefringence $\langle \Delta n_{\mathrm{eff}} \rangle$ and corresponding averaged effective polar angle θ for the experimental data on transmitted light intensity shown in figure 1 ($t_{\mathrm{er}} = 0$).

Rec. time/min	$\langle \Delta n_{\mathrm{eff}} \rangle$	θ/°
5	9.74×10^{-3}	80.79
10	9.0×10^{-3}	71.65
20	8.0×10^{-3}	63.54
40	7.76×10^{-3}	61.87
60	7.69×10^{-3}	61.40

Table 2. Averaged effective birefringence $\langle \Delta n_{\mathrm{eff}} \rangle$ and corresponding averaged effective polar angle θ for the experimental data on transmitted light intensity shown in figure 2 ($t_{\mathrm{rec}} = 10$ min).

Erasure time/min	$\langle \Delta n_{\mathrm{eff}} \rangle$	θ/°
0	9.0×10^{-3}	71.7
10	9.60×10^{-3}	78.58
20	9.74×10^{-3}	80.68
40	9.74×10^{-3}	80.68
60	9.74×10^{-3}	80.68
80	9.74×10^{-3}	80.68

varies very slowly and is about half (e.g. $I^{\mathrm{tr}} = 10$ arb.un.) that of the transmitted light passing through the memorized pictures in the nematic state (e.g. $I^{\mathrm{tr}} = 20 \pm 2$ arb.un. in all optical configurations). This result means that SmC, although known to be a more ordered system in a bulk structural sense, seems to be more disordered by a factor of two. This implies that the surface anchoring in the smectic C phase is about a factor of two smaller. In the optical polarization sense, this means that the smectic C state, where the pictures are recorded, is a more opaque system than the nematic state where the pictures are stored. This means also that the contrast between the recorded SmC texture, which has to be erased, and the N texture is quite big, which is very important for display systems. Figure 2 shows the transmitted light intensity through the memorized smectic C texture in the nematic temperature range as a function of the recording time $I^{\mathrm{tr}} = I^{\mathrm{tr}}(t_{\mathrm{rec}})$ for the optical configuration (c) (the liquid crystal stage is not rotated) and figure 3 gives the transmitted light intensity through the memorized smectic C texture in the nematic range as a function of the erasure time $I^{\mathrm{tr}} = I^{\mathrm{tr}}(t_{\mathrm{er}})$. As can be seen, the variation of I^{tr} is rather small and especially in the erasure stage is almost negligible. We would like to interpret this effect through some surface parameters which can be controlled by the nature of the orienting surface coatings. One important conclusion from this effect is that we visually detect the macroprocess (different oriented pictures) by polarization microtextural analysis, but we are unable to detect the successive microprocesses which continue when the recording time increases. Such a microprocess which can develop at the solid surface–liquid crystal interface is the variation of the surface director orientation $\mathbf{n}_s$, expressed by the polar θ and azimuthal φ angles. Since we imposed $\mathbf{n}_o$ (easy direction) by rubbing, we assume that φ is almost zero. The variation of θ with the variation of t_{rec}, however, can be detected (although very weakly) by some typical optical parameters like the effective birefringence $\Delta n_{\mathrm{eff}}(\theta)$, averaged over the entire cell. In tables 1 and 2 we show the effective birefringence variation due to different recording and erasure times, respectively. Consequently, the birefringence variation represents the variation of the angle θ. Changing the recording time values, we record different $\langle \Delta n_{\mathrm{eff}} \rangle$ values or accumulate data about the averaged angle θ. In the interval $0 < t < 25$ min ($t = t_{\mathrm{rec}}$ or t_{er}), $\theta(t)$ linearly decreases or increases, respectively; and for $t > 25$ min $\theta(t)$ is nearly constant—saturated.

In the proposed experiment we also detect that the transmitted light intensity in the case of the smectic C phase is a factor of two smaller than that in the nematic phase. Since we assume that it is mainly the polar angle θ that varies, one can conclude that the effective averaged polar angle in SmC is smaller than that in the nematic state. Considered as ordering, this means that on going to the nematic state, where the oriented smectic C texture is stored, the bulk ordering increases. The very small variation of I^{tr} and $\langle \Delta n_{\mathrm{eff}} \rangle$ with variation of t_{rec} indicates a very small variation of the polar angle θ and a θ value close to $\pi/2$, meaning strong anchoring. The interval of accumulation of θ values is depressed for strong anchoring in our case, as can be concluded from tables 1 and 2. As already mentioned, the values of θ changes linearly, going to saturation at about 25 min. One can conclude that further thermal treatment is unable to change the surface conditions or that this value (25 min) demonstrates the region where—undetected by the microtextural optical polarization process—stabilization of the memorization on a microlevel is achieved. For longer times for t_{rec} or t_{er}, respectively, the variation of θ and the stabilization of the memorized texture on the microlevel are terminated. One point of specific interest in the interval from 0 to 25 min is the value $t^* = 10$ min. At this point the linear parts of the recording and erasure time dependences $\theta(t_{\mathrm{rec}})$, $\theta(t_{\mathrm{er}})$ intersect (say at $\theta = \theta^*$), which implies that for our chosen anchoring, the θ values could be equalized for suitable equal recording and erasure times. It will be interesting to study the control of this point by varying the anchoring strength.

It can be concluded that in order to obtain a more sensitive variation of I^{tr} and $\langle \Delta n_{\mathrm{eff}} \rangle$, the anchoring must be weak, thus giving the possibility of varying the effective averaged polar angle θ (as well as the angle φ) over a wide range, implying variation of the recorded data over such a wide region. Certainly achieving a well controlled weak anchoring is a difficult but attractive problem, and its realization will be the aim of our future studies.

3. Conclusion

We have presented a method for indicating the accumulation of recorded oriented textures in the smectic C phase and their storage (by the process of the surface memorization) in the nematic range. We call this effect the 'multipages effect'. The recorded accumulated pictures are identified with the surface conditions—the polar and azimuthal angles θ and φ (for strong anchoring only θ is effective). The interval for recorded and accumulated pictures is assumed to increase when the anchoring energy is weak.

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