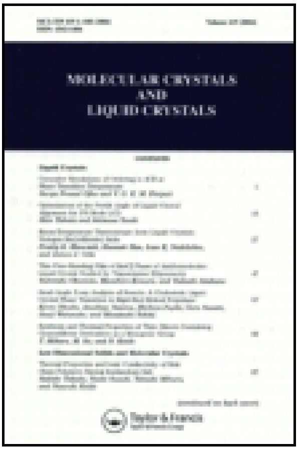

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 360, pp. 193-201
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Light-Controlled Anchoring Energy in Nematic Liquid Crystals

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In this paper we show the possibility of regulating the dose of the anchoring energy under the control of the incident light. Using a dye-doped nematic sample where it was previously demonstrated the effect of light-induced anchoring, we measured the threshold for the Fredericksz transition for different irradiation times using a low power laser beam. Our data compare favourably to the existing theory and show that the amount of induced anchoring energy increases linearly with the irradiation time.

Keywords: dye doped liquid crystals; light-induced anchoring

INTRODUCTION

After the first paper of Ichimura [1] a strong effort has been devoted to study efficient mechanisms to control the orientation of the liquid crystal (LC) director at a LC-solid interface by light irradiation. Most of the work has concerned with coating the surface with photo-sensitive materials that undergo molecular transformations induced by light absorption. These light-induced transformations usually correspond to a change of shape of the photo-sensitive material (e.g. via *trans-cis* isomerisation) which in turn affects the director orientation near the surface. In this way, the easy axis on the surface is controlled by light and, as a consequence, the LC orientation throughout the cell is determined. Accordingly, it is possible in principle to control the strength of anchoring, the azimuthal orientation and the pre-tilt angle of the director. A different reorientation phenomenon has been reported by Reznikov and coworkers [2]. They demonstrated the possibility of inducing an easy axis over an originally isotropic surface as a consequence of light excitation of a small quantity of azo-dye dissolved in the bulk of a liquid crystal cell. This effect has been shown to be very efficient to record high resolution intensity [3] and polarization gratings [4], with a sensitivity higher than that found in other materials of interest for optical recording.

In this paper we report the evidence that, by exploiting this effect, it is possible to control the amount of anchoring energy on a liquid crystal substrate without inducing any director reorientation. This result is obtained by detecting the Freedericksz transition in the same liquid crystal cell, under different excitation conditions.

EXPERIMENTAL

The LC cell used in the experiment was 20μm thick and consisted of a mixture of nematic 5CB and the azo-dye Methyl-Red (≅1% in weight). The inner surfaces of the two glass substrates (both coated by ITO) were treated in different ways. The reference surface was coated by polyimide and mechanically rubbed to get strong planar anchoring. The control surface was coated by polyvinil-cinnamate-fluoride (PVCN-F) to provide a negligibly small azimuthal anchoring. The reference surface originally imposed an homogeneous planar alignment throughout the whole cell. In all the experiments the pump beam was provided by He-Cd laser (λ=0.442 μm, P= 1 mW) slightly focused on the cell from the side of the control surface.

In order to check the occurrence of the light-induced anchoring effect a preliminary series of measurements was performed by the conventional pump-probe technique. The director orientation over the control surface was detected by checking the polarization state of an He-Ne laser probe beam (λ=0.633 μm, P= 1 mW) impinging on the cell from the side of the reference surface. The pump field $\mathbf{E}_p$ of the probe beam was set parallel to the initial director orientation $\mathbf{n}_0$ and the signal transmitted through the crossed analyser was detected. Since in these experimental conditions the adiabatic conditions are fulfilled, the direction of the field $\mathbf{E}_p$ followed the director $\mathbf{n}(z)$ while propagating through the cell and, as a consequence, any rotation of the director over the control surface (up to 90°) led to an increase of the transmitted signal. The intensity of this latter is simply given by $I_d=I_0\sin^2\alpha$, where I_0 is the intensity of the probe beam before the analyser and α is the azimuthal angle between the director orientation on the control surface $\mathbf{n}_c$ and the one on the reference surface $\mathbf{n}_0$; more details on the experimental geometry and technique have already been reported [2]. A typical result of the above described measurements is shown in fig.1, where the

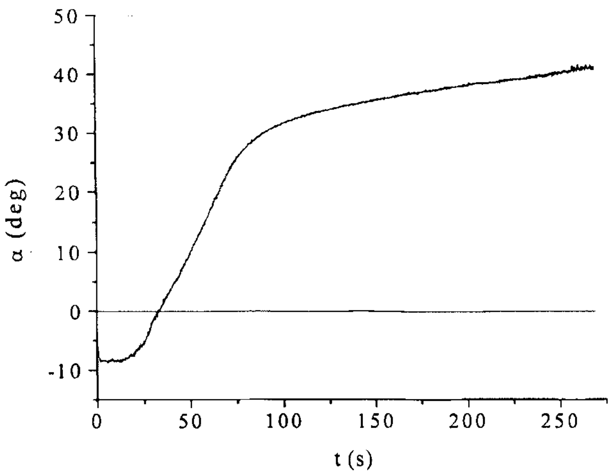

Figure 1: Surface director reorientation angle α versus the exposure time t. The angle between the polarization of the pump beam and $\mathbf{n}_0$ is 45°

reorientation angle α vs the exposure time is reported. The time t=0 corresponds to the switch-on of the pump beam. In the first part of the curve it is $\alpha < 0$, i.e. the molecular director rotates away from the pump polarization direction [5]. After reaching the value $\alpha = 0$, the effect of easy axis formation along a direction parallel to the pump polarization becomes more and more effective, since for higher and higher exposure times the director orientation over the control surface approaches the direction of the pump beam polarization. The twisted configuration obtained through the cell after director reorientation is extremely stable: no change was detected after several months from irradiation. These results find a satisfactory explanation considering the adsorption of excited dye molecules on the surface as the basic mechanism for the induced anchoring [5]. According to this model, the main features of the light-induced adsorption are the following: (i) it gives rise to an easy axis parallel to the pump beam polarization, (ii) it gives rise to an anchoring energy dependent on the exposure time.

FREDERICKSZ TRANSITION

In order to demonstrate the second issue raised in the former section, measurements of the threshold for Fredericksz Transition were performed. In fact, it is well known that the anchoring energy affects the threshold field necessary for the transition, which increases as the anchoring energy becomes higher. In order to investigate only the effect of anchoring energy increase due to light irradiation without inducing any director reorientation, the polarization of the exciting beam was set parallel to the initial planar orientation. In this way, the easy axis was generated in the same direction and no director reorientation at the surface was induced, the only effect being the possible increase of the anchoring energy at the control surface. Such increase would be detectable by using a conventional observation of the Fredericksz transition. The order transition was induced by a d.c. electric field obtained applying a suitable voltage across the cell substrates; the probe beam from a He-Ne laser had a polarization at 45° with respect to the initial director orientation.

In this way, the phase shift due to the electrically induced distortion between the ordinary and the extraordinary wave gave rise to a signal transmitted through the crossed analyser.

The transmission characteristic of the sample was recorded for different exposure times t_0 of the He-Cd laser beam. In fig.2 we report an example of such measurements: the transmission curves for two different exposure times are plotted (t_0=0 s and t_0=8 min). In this figure it is evident the huge variation of threshold for the Freedericksz transition, which cannot be ascribed to a big change of pretilt angle that is generally related to the initial slope of the curve, being the two slopes very similar.

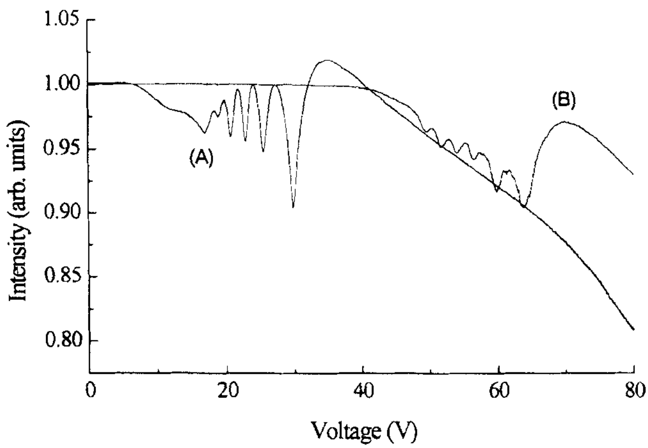

Figure 2: Intensity of the detected signal vs the applied voltage. Curve (A) : before pre-illumination ; curve (B) : after 8 minutes of pre-illumination.

These results can be discussed considering the problem theoretically addressed several years ago [6] : how the anchoring energy affects the threshold for the Freedericksz transition? Under the constraint of a fixed voltage, the generalized threshold for a LC cell with finite anchoring energy on the boundary walls has been obtained. Calling θ the tilt angle with respect to the boundary normal (boundaries placed at z= ± d/2) the equation to be solved is:

$$\frac{d^2\theta}{dz^2} + \xi^{-2}\theta = 0 \tag{1}$$

with the boundary conditions:

$$\begin{cases} \dfrac{d\theta}{dz} - \dfrac{\theta_1}{L_1} = 0 & at \quad z = -\dfrac{d}{2}, \theta_1 = \theta\left(-\dfrac{d}{2}\right) \\ \dfrac{d\theta}{dz} + \dfrac{\theta_2}{L_2} = 0 & at \quad z = \dfrac{d}{2}, \theta_2 = \theta\left(\dfrac{d}{2}\right) \end{cases} \tag{2}$$

where $L_1=K/W_1$, $L_2=K/W_2$ are the extrapolation lengths, K is the elastic constant (in the one constant approximation), W_1 and W_2 are the anchoring strengths on the two boundaries defined through the surface energy $f^S_{1,2} = \frac{1}{2}W_{1,2}\cos^2\theta_{1,2}$.

In eq. (1) ξ^{-2} is the parameter that takes into account the interaction with the electric field. Its expression depends on the experimental geometry; in our case (planar sample with positive dielectric anisotropy, electric field parallel to the cell boundaries) it is

$$\xi^{-2} = \left(\frac{\varepsilon_\perp}{\varepsilon_{//}}\right)^2 \frac{\Delta\varepsilon E^2}{4\pi K} \tag{3}$$

The general solution of eq.(1) is $\theta(z) = A\sin(z/\xi) + B\cos(z/\xi)$, where A and B are two integration constants.

Using this equation in the boundary conditions (2), a system of homogeneous equations for A and B is obtained. In order to get not trivial solutions, the determinant of coefficients has to vanish. In this way the condition for the critical field is obtained:

$$tg\left(\frac{d}{\xi_2}\right)=\frac{(L_1+L_2)\xi_c}{L_1L_2-\xi_c^2} \tag{4}$$

In case of one strong boundary ($W_2=\infty$) and one weak boundary ($W_1=W$) we get:

$$tg\left(\frac{d}{\xi_2}\right)=-\frac{L_1}{\xi_c} \tag{5}$$

which can be written as:

$$tg(\gamma E_c)=-\frac{E_c}{W_1}\gamma' \tag{6}$$

where $\gamma=d\sqrt{\Delta\varepsilon/4\pi K}$, $\gamma'=(k/d)\gamma$ and E_c is the threshold field for the Fredericksz transition. This equation can be numerically solved to get the threshold field vs the anchoring energy W_1. The behavior of this theoretical curve can be compared to our experimental data. In fact from the curves shown in fig.2 is possible to get the threshold voltage for different pre-illumination time. This plot is reported in fig.3 for a sample where a more complete set of data was taken. It should be underlined here that the high values of the measured thresholds are associated to the existence of free charges in the sample due to the presence of the dye. In fact the application of a c.w. electric field induces a charge separation and a consequent opposite space-charge field that reduces the actual field on the molecules. As shown in a former investigation on light-induced anchoring [5], the dependence of the induced anchoring energy W on t_0 can be approximated as linear for low pre-illumination times t_0:

$$W=c\,t_0+d \tag{7}$$

where d plays the role of an intrinsic anchoring energy, i.e. the anchoring energy at zero pre-illumination time. Figure 3 shows the threshold field vs. pre-illumination time. The filled circles represent the experimental data whereas the continuous line reports the best fit to the experimental data obtained by numerical solution of eq.(6) and using eq.(7) to convert the W scale to the t_0 scale. The values of c=4.8x10^{-4} erg/s and d=1.0x10^{-4} erg used in the latter equation have been determined by a least square minimization procedure. A good agreement between theory and experiment is obtained. However, it must be observed that the anchoring energy values predicted by our model are much smaller than typical values of the most commonly used interfaces. This apparent discrepancy should be related to the peculiar nature of the PVCN-F surface. In fact, the observed smallness of the polar anchoring energy W is probably related to the negligibly smallness of the azimuthal anchoring energy, which is a peculiar characteristic of the surface. Direct measurements of the surface anchoring energies are planned to confirm our interpretation.

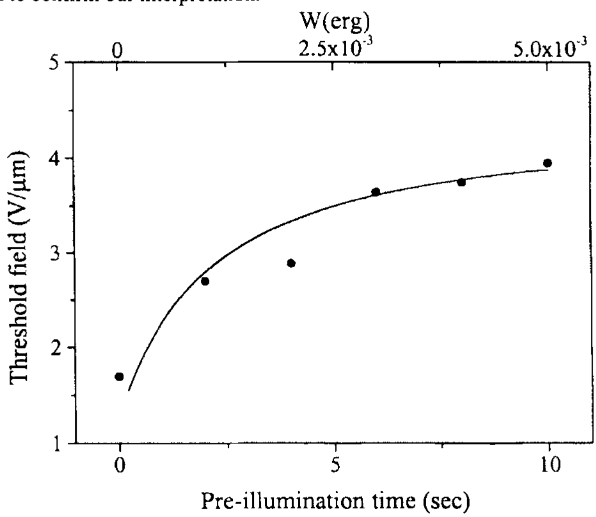

Figure 3: Threshold field vs pre-illumination time. Full line is obtained by solving equation (6)

CONCLUSIONS

In conclusion we have demonstrated that the previously reported effect of light-induced anchoring in 5CB doped by Methyl-Red corresponds to an increase of anchoring energy with the irradiation time. The measurements of threshold for the Fredericksz transition show that it can be easily controlled by the light. This result is very interesting in view of applications for a new kind of LC optical devices.

ACKNOWLEDGEMENTS

We acknowledge support of MURST through Project PRIN, 9802010369 and by EC in the frame of INCO Copernicus Concerted Action "Photocon" under contract N° IC 15-CT98-0806

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