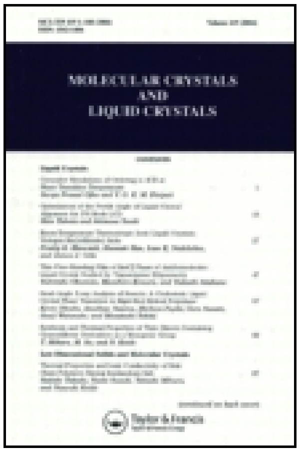


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Laser Induced Configurational Transition in Liquid Crystals

Gongjian Hu [a] & P. Palffy-muhoray [a]
[a] Department of Physics, Liquid Crystal Institute, Kent State University, Kent, OH, 44242

Version of record first published: 04 Oct 2006

To cite this article: Gongjian Hu & P. Palffy-muhoray (1997): Laser Induced Configurational Transition in Liquid Crystals, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 304:1, 447-453

To link to this article: http://dx.doi.org/10.1080/10587259708046995

Mol. Cryst. Liq. Cryst., 1997, Vol. 304, pp. 447–453
Reprints available directly from the publisher
Photocopying permitted by license only

LASER INDUCED CONFIGURATIONAL TRANSITION IN LIQUID CRYSTALS

Gongjian Hu and P. Palffy-Muhoray

Liquid Crystal Institute and Department of Physics, Kent State University, Kent, OH 44242

We have investigated the reorientation of NLC in thermal gradient field. The nonuniform temperature field is produced by focusing He-Ne laser on a dye doped homeotropically aligned LC cell. A new physical mechanism is proposed, where the reorientation is resulting from the surface torque produced by order-electric effect. The calculation of free energy shows this configurational transition is second order. The theoretic analysis and experimental observation of reorientation induced by angular momentum of light field in dye doped NLC are also reported.

DIRECTOR REORIENTATION INDUCED BY ORDER-ELECTRIC EFFECT

1) In nematics the divergence of permittivity induces a polarization which encompasses both flexo- and order-electric effects.

$$\mathbf{P} = cS\Delta\epsilon_a\{\mathbf{n}(\nabla\cdot\mathbf{n}) - \mathbf{n}\times\nabla\times\mathbf{n}\} + c\Delta\epsilon_a\frac{dS}{dT}\{(\mathbf{n}\cdot\nabla T)\mathbf{n} - \frac{1}{3}\nabla T\} \qquad (1)$$

where S is scalar order parameter. c is a constant. $\Delta\epsilon_a = (\epsilon_{\|} - \epsilon_{\perp})_{\max}$. To the lowest order the relationship between flexo-electric coefficient f_e and order- electric coefficient f_o is $f_e = Sf_o = cS\Delta\epsilon_a$. In an uniformly aligned nematic cell, scalar order parameter S is a function of temperature, that gives $\nabla S = \frac{dS}{dT}\nabla T$.

2) Doping liquid crystal with a small amount of dye enhances the light absorption, which creates a large ∇T. The temperature field distribution is obtained by solving thermal diffusion equation.

3) In absence of external electric field, due to the existence of order-electric polarization, there is a depolarization field acting on liquid crystal. For the geometry shown in Fig.1, electric field in sample is $E_z \approx -\frac{\tau P_z}{\epsilon_0}$, $E_y = E_x = 0$, where τ is a depolarization factor. For a thin liquid crystal layer with uniform polarization normal to the layer, τ equal to unity.

Now the free energy of the system consists of elastic, electric and interfacial contributions. If the electric contribution to the free energy is sufficiently large, director reorientation reduces the free energy. The free energy of the system is

$$F = \int\{\frac{1}{2}K(\frac{d\theta}{dz})^2 + \frac{1}{2}\frac{\epsilon_{zz}P_z^2}{\epsilon_0}\}dV + w\sin^2\theta_s \qquad (2)$$

Assuming $K = 6.5\times10^{-12}N$, $f_o = 3\times10^{-11}C/m$, $S_{avg}\approx 0.7$, $L = 25\mu m$, $w = 10^{-5}J/m^2$, Euler-Lagrange equation is solved numerically. Results are shown in

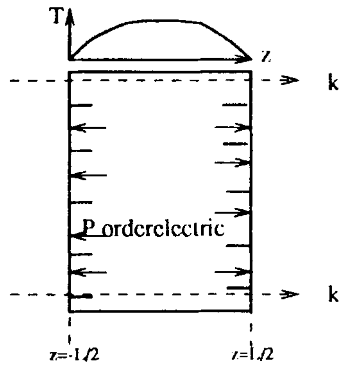


Fig.1. Order electric effect in guest-host system.

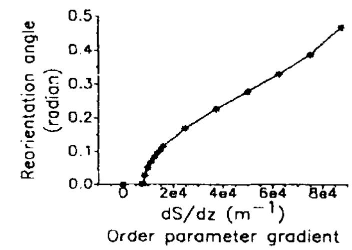


Fig.2. Reorientation angle of director as function of order parameter gradient on interface.

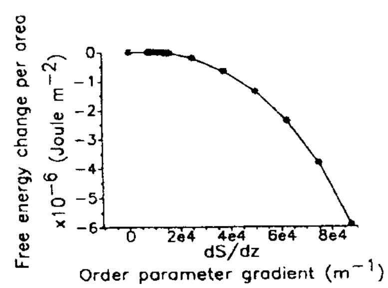


Fig.3. Free energy per area as function of scalar order-parameter gradient on interface.

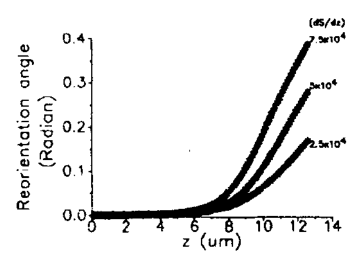


Fig.4. Reorientation angle as function of position.

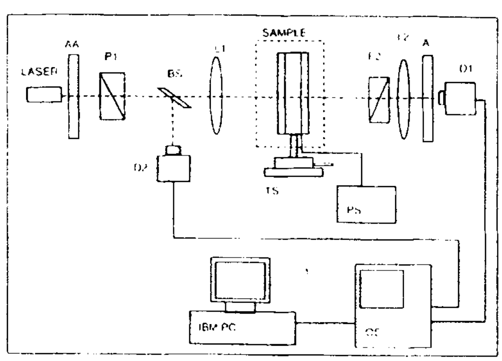


Fig.5. Experimental setup. A, attenuator. AA adjustable attenuator P1,P2, polarizers; L1,L2, lens; D1,D2 photodiode detectors; TS, translation stage; PS power supply; BS, beam splitter; OS, oscilloscope; S, shutter; TC, temperature controller.

Figs.2-4. The configurational transition is second order. Director reorientation is driven by surface torque. The threshold of order parameter gradient is estimated

$$(\frac{dS}{dz})_{\max\ \mathrm{thr}} = \frac{3\epsilon_0 w}{4f_o^2(S_3^{\frac{2}{3}}\Delta\epsilon_a + \bar{\epsilon})S} = 6.5 \times 10^3 m^{-1}. \tag{3}$$

4) Including Debye screening, considering sample at focal point, $\tau \sim \frac{1}{3}$, the director is found to be tilted at $\theta = 35.3°$. This realignment produces a change in the absorption coefficient

$$\Delta\alpha = (\alpha_{\|} - \alpha_{\perp})\sin^2\theta\frac{1}{2} \simeq \frac{1}{6}(\alpha_{\|} - \alpha_{\perp}) \tag{4}$$

and in the intensity of transmitted light

$$I = I_0 \exp(-\frac{r^2}{\omega^2})\sin^2\frac{\delta}{2}\sin^2 2\phi, \tag{5}$$

where δ is the phase shift between ordinary and extraordinary waves. In a uniformly aligned cell $\delta = I = 0$. After reorientation $\delta = \frac{2\pi}{\lambda}(n_e - n_o)L$.

5) From time-dependent Ginzburg-Landau equation, the rise time of the system is estimated to be $\sim 2ms$.

6) Linear stability analysis shows that director reorientation can also occur in planar aligned cell.

EXPERIMENT

Samples consisted of $25\mu m$ thick slabs of homeotropically aligned E7-D27 mixture between parallel ITO coated glass plates. The experimental setup is shown in Fig.5.

Typical open aperture Z-scan results for a homeotropically aligned cell are shown in Fig6. The measured threshold intensity for both linearly and circularly polarized light is $I_{th} = 2.9 \times 10^6 W/m^2$. Using the values $P = 13mW$, $\omega = 38um$, $\alpha = 1 \times 10^4 m^{-1}$, $\frac{dS}{dT} \approx 0.01\ °C^{-1}$, $L = 25um$, the threshold order parameter gradient is

$$(\frac{dS}{dz})_{\max\text{-}\mathrm{thr.}} = 9 \times 10^3 m^{-1}.$$

With the sample at the focal point, beam waist $\omega_0 = 11\mu m$, our model predicts that $\Delta\alpha = 0.73 \times 10^4 m^{-1}$, while $\alpha_{eff} = \alpha_{\perp} + \Delta\alpha = 1.58 \times 10^4 m^{-1}$, see Fig.7.

Fig.8. shows the observed pattern. After the configurational transition the director has nonzero $\hat{z}$ and $\hat{r}$ components.

For positive materials, an electric field applied normal to the cell walls will favor homeotropic orientation. As the applied voltage increases, we expect that reorientation induced by the order-electric effect will be suppressed. This has been observed.

The measured rise time of the system is $\sim 5ms$, as shown in Fig.9. The director reorientation in planar aligned cell is also observed in experiments.

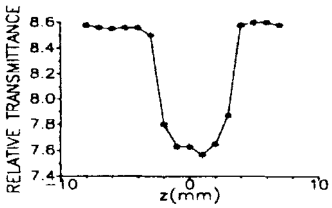


Fig.6. Transmittance as function of sample position z. The incident light is linearly polarized, $\mathbf{E} \perp \mathbf{n}$.

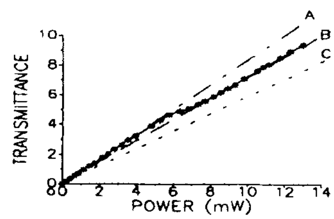


Fig.7. Transmittance as function of incident laser power. Line OA corresponds to $I_{out}=I_{in}\exp(-\alpha_{\perp} L)$, OB to $I_{out}=I_{in}\exp(-\alpha_{eff} L)$, OC to $I_{out}=I_{in}\exp(-\alpha_{iso} L)$.

Fig. 8. Far field diffraction pattern. The hometropic aligned sample is between crossed polarizers, $\mathbf{E} \perp \mathbf{n}$, Observed pattern is induced by configurational transition.

(See Color Plate XIX).

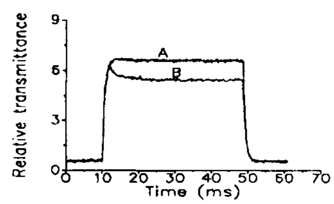


Fig.9. The optical response of a homeotropic aligned D27-E7 sample, $\mathbf{E} \perp \mathbf{n}$, A is for sample on far field. B is for sample on focal point.

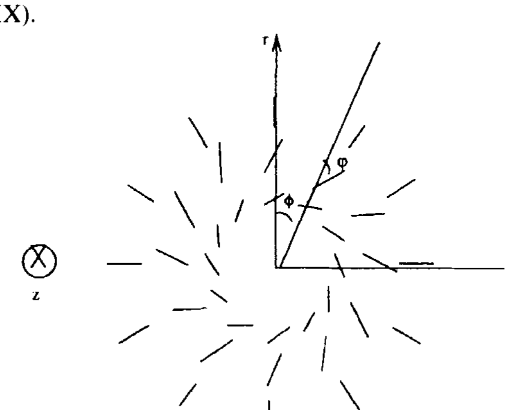


Fig. 10. Director distortion induced by right handed circularly polarized light.

DIRECTOR REORIENTATION INDUCED BY ANGULAR MOMENTUM OF LIGHT FIELD

When a circularly polarized light is absorbed by the dye, angular momentum is transmitted causing the dye molecules to reorient. During the order electric configurational transition, the angular shift of $\hat{r}$ component of the director breaks the cylindrical symmetry of the system (Fig.10) and produces a change in the birefringence. The change of angular momentum of the light field gives the torque balance equation

$$\frac{1}{4}K(\frac{1}{r}\frac{d\varphi}{dr}+\frac{d^2\varphi}{dr^2})+\Gamma=0. \tag{6}$$

If Γ is independent of r,

$$\varphi=N\pi+2\times10^{-2}\Gamma r/K-2\Gamma r^2/K. \tag{7}$$

EXPERIMENTAL OBSERVATION AND NUMERICAL SIMULATION

Fig.11 shows the geometry used to measure the circular depolarization of light due to director reorientation induced by both the order electric effect and the transfer of angular momentum from light field. We observe a spiral depolarization pattern at the far field. Figs.12a – 12b. As the circular polarization of the input beam is changed from left to right-handed, the angular momentum of the light field changes direction, and so does the spiral.

The far field pattern can be simulated by using the Jones matrix formalism. If ψ satisfies

$$\sin^2\frac{\delta}{2}=\psi\sin\delta, \tag{8}$$

the depolarized light intensity is

$$I_d=\sin^2(\Theta) \tag{9}$$

where

$$\Theta=\phi+N\pi+1.2\times10^{-2}\Gamma r/K-\frac{1}{2}\Gamma r^2/K. \tag{10}$$

The results of simulation is shown in Fig.12c – 12d. Changing the sign of angular momentum, the spiral reverses its direction.

SUMMARY

We have proposed a model of thermal gradient induced order-electric polarization and configurational transition in nematic liquid crystals. We have demonstrated that this effect is independent of the polarization of the incident radiation. We have shown that the transition can be suppressed by an applied electric field.

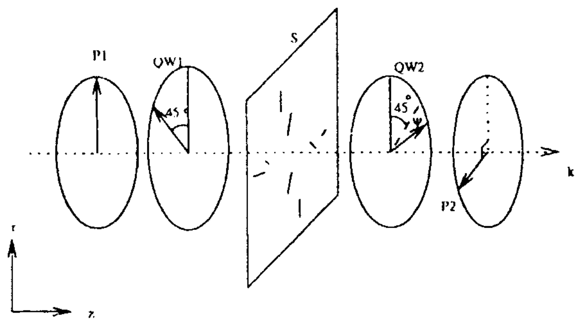


Fig. 11. Geometry used to observe the spiral depolarization pattern induced by right handed circularly polarized light. P1 and P2 are polarizer and analyzer QW1, QW2 are λ/4 waveplates. Optic axis of QW1 and QW2 are represented by arrows line. S is a sample.

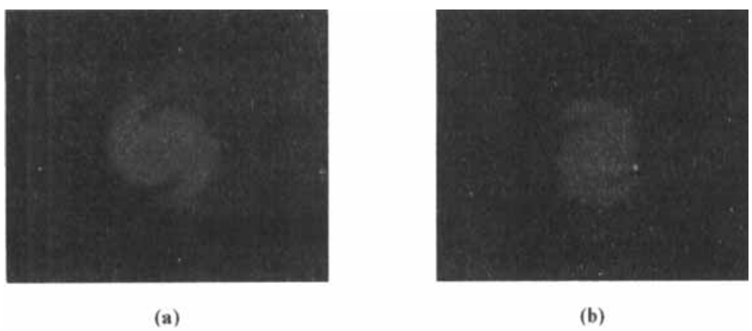
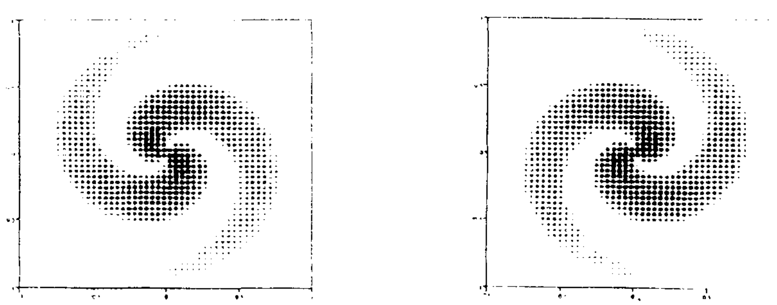


Fig.12a,12b. The far field depolarization pattern induced by order electric effect and angular momentum of light field. (a) the incident beam is right circularly polarized . (b) The incident beam is left circularly polarized (See Color Plate XX).



(c) (d)

Fig.12c,12d. Simulation of the far-field pattern. (c) Incident beam right circularly polarized. (d) Incident beam is left circularly polarized.

Theoretical predictions of threshold intensity for reorientation and absorption change and the rise time of the system are in good agreement with experimental measurements.

We have considered director reorientation driven by the transfer of angular momentum from optical field. Starting from the torque balance equation, we have calculated the director field. We designed the experiments to observe distorted director field via spiral shaped patterns. We have carried out simulations of far field pattern from the computed director field. The theory is in good agreement with the experimental observations.

We acknowledge support from the NSF under ALCOM grant DMR89-20147.

REFERENCES

[1] Meyer R.B., *Phys. Rev. Lett.* **22**, *918,1969.*

[2] Barbero G,, Dozov I., Palierne J.F., Durand G., Phys. Rev. Lett., **56**, 2056, 1986.

[3] Janossy J., *Mol. Cryst. Liq Cryst.,* **207**, 189, 1991.

[4] Derzhanski A., Petrov A.G., and Mitov M.D., *J. Phys.(France)*, **39**, 273, 1979.

[5] Santamato E., Abbate G., Maddalena P., Shen Y. R., Phys. Rev. A **36**, 2389, 1987.