Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713926090

On the relationship between electro-optic and dielectric parameters of a smectic C* ferroelectric liquid crystal

Yu P. Kalmykov[a,b]; J. K. Vij[a]
[a] Department of Microelectronics and Electrical Engineering, University of Dublin, Trinity College, Dublin, Ireland [b] Institute of Radio Engineering & Electronics of the Russian Academy of Sciences, Moscow Region, Russia

To cite this Article Kalmykov, Yu P. and Vij, J. K.(1994) 'On the relationship between electro-optic and dielectric parameters of a smectic C* ferroelectric liquid crystal', Liquid Crystals, 17: 5, 741 — 744
To link to this Article: DOI: 10.1080/02678299408037345
URL: http://dx.doi.org/10.1080/02678299408037345

LIQUID CRYSTALS, 1994, VOL. 17, NO. 5, 741–744

PRELIMINARY COMMUNICATION

On the relationship between electro-optic and dielectric parameters of a smectic C* ferroelectric liquid crystal

by YU P. KALMYKOV† and J. K. VIJ*

Department of Microelectronics and Electrical Engineering, University of Dublin, Trinity College, Dublin 2, Ireland

(*Received 31 January 1994; accepted 2 April 1994*)

A relationship between the electro-optic switching time and dielectric parameters of a S_C^* ferroelectric liquid crystal (FLC) is obtained. This relationship is derived in terms of spontaneous polarization P_s, relaxation time τ_G and dielectric strength $\Delta\varepsilon_G$ of the Goldstone mode. It shows clearly that the switching phenomenon in FLCs is governed by the dielectric behaviour of the Goldstone mode. Based on the Landau model, the switching time has also been related to the material parameters of the FLC.

Ferroelectric liquid crystals (FLCs) in the surface stabilized geometry offer high speed, high contrast and bistable electro-optic switching characteristics. As a consequence, these have a variety of applications in practice (light control in the laboratory, in fibre optics, in data processing etc.) [1–3]. The surface stabilized geometry allows the suppression of the intrinsic helix of FLCs and produces two stable states with opposite spontaneous polarizations, P_s [4]. These states can readily be switched with a time constant of a few μs by applying a relatively small constant external field E. In this paper, we present a derivation for the switching time in terms of the dielectric parameters of the Goldstone mode. The switching time will be related to the material parameters using the Landau model.

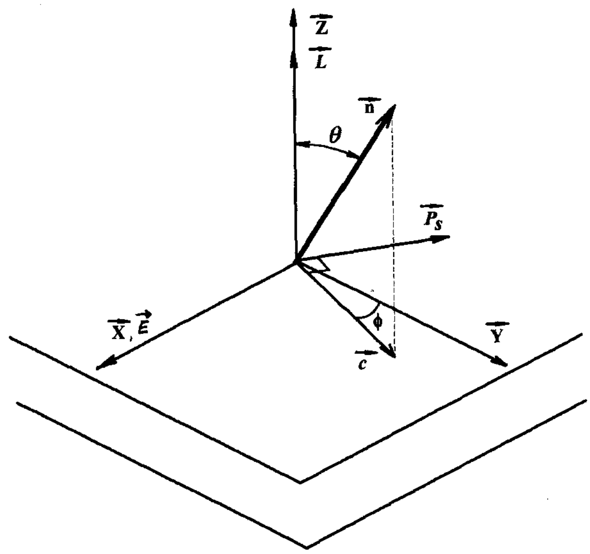
The study of the electro-optical switching of the S_C^* phase is based on the following equation [2, 3]

$$\gamma \frac{\partial}{\partial t} \phi = K \frac{\partial^2}{\partial z^2} \phi - P_s E \sin \phi, \tag{1}$$

where ϕ is the azimuthal angle that determines the position of the tilt, γ is the rotational viscosity with respect to a rotation about the smectic layer normal **L**, which defines the Z direction (the smectic layers define the XY plane, see the figure), K is the isotropic or mean elastic constant, P_s is the magnitude of spontaneous polarization of the S_C^* FLC, and E is the amplitude of the applied electric field **E**. We assume that the sample has

* Author for correspondence.

† Permanent address: Institute of Radio Engineering & Electronics of the Russian Academy of Sciences, Vvedenskii Sq 1, Fryazino, Moscow Region, 141120, Russia.



X, Y, Z-coordinate system; **n**, molecular director; **L**, smectic layer normal; **c**, **c** director (projection of **n** on to smectic layer plane); $\mathbf{P}_s$, spontaneous polarization vector; θ, molecular tilt angle; ϕ, azimuthal angle, X–Y smectic layer; **E** is applied along **x**.

been aligned in the bookshelf geometry using an appropriate alignment technique and that the viscosity γ of the sample corresponds to the bulk viscosity of the FLC.

It has been confirmed by experiment [5, 6] that both the normal **L** and the tilt angle θ between the director vector **n** and the layer normal vector **L** do not change during the application of an electric field parallel to the layers. Let the FLC be in a stable state brought about by applying a small DC field; we then switch it to the second state by reversing the polarity of the electric field. The director rotates around **L**, at a constant tilt angle θ and this assumes an opposite position on the cone, i.e. the azimuthal angle is changed from ϕ to $\phi + \pi$.

This molecular reorientation can collectively take place in the bulk and the entire macroscopic polarization $\mathbf{P}_s$ is then effective in the driving torque $\mathbf{P}_s \times \mathbf{E} = P_s E \sin\phi$ [5]. The solution of equation (1) for the spatially uniform case is given by

$$\phi(t) = 2\tan^{-1}\left[\tan\left(\frac{\phi(0)}{2}\right)\exp\left(-\frac{t}{\tau}\right)\right]. \tag{2}$$

For large t equation (2) predicts a pure exponential (decay for $\phi(t)$), viz.

$$\phi(t) \cong 2\tan\left(\frac{\phi(0)}{2}\right)\exp\left(-\frac{t}{\tau}\right), \tag{3}$$

with the relaxation time, τ, given by

$$\tau = \gamma / P_s E. \tag{4}$$

This result is also given by Clark and Lagerwall [3, 5].

The collective molecular motion in the S_C^* phase with a constant tilt angle θ is known as the Goldstone mode [7]. As shown in [8], the equation (1) describing the phenomenon of switching allows us to derive an expression for the contribution of the Goldstone mode to the complex dielectric susceptibility $\chi_G(\omega)$ of the S_C^* phase of the FLC. This contribution is given by [8]

$$\chi_G(\omega) = \frac{\varepsilon_0 \Delta\varepsilon_G}{1 + i\omega\tau_G}, \tag{5}$$

where $\Delta\varepsilon_G$ and τ_G are the dielectric strength and the relaxation time of the Goldstone mode respectively, which are defined as

$$\Delta\varepsilon_G = \frac{P_s^2}{\varepsilon_0 2Kq^2} \tag{6}$$

and

$$\tau_G = \frac{\gamma}{Kq^2}. \tag{7}$$

ε_0 is the permittivity of free space, and q is the modulus of the wavevector $\mathbf{q}$ of the unperturbed pitch. Here it is assumed that the rotational viscosity γ which refers to the rotation about the layer normal $\mathbf{L}$ differs from the Goldstone mode rotational viscosity γ_G; the latter refers to a uniform rotation about an axis perpendicular to both $\mathbf{n}$ and P_s [6]. As γ and γ_G transform like components of a tensor, they are related by [6]

$$\gamma = \gamma_G \sin^2\theta, \tag{8}$$

where it is assumed that the rotational viscosity for rotation around the director $\mathbf{n}$ is negligibly small in comparison with γ_G.

On combining equations (4), (6) and (7) we readily derive an expression for the switching time τ, viz.

$$\tau = \frac{\tau_G P_s}{2\varepsilon_0 \Delta\varepsilon_G E}. \tag{9}$$

The main feature of equation (9) is that τ depends only on the dielectric parameters τ_G, $\Delta\varepsilon_G$ and P_s. These parameters can be measured experimentally [8, 9]. Thus we can calculate the electro-optic switching time τ independently from dielectric measurements of spontaneous polarization P_s, Goldstone-mode dielectric strength $\Delta\varepsilon_G$ and relaxation time τ_G. Equation (9) clearly establishes that τ is governed by the dielectric parameters for the Goldstone mode.

The dielectric parameters τ_G, $\Delta\varepsilon_G$ and P_s appearing in equation (9) can also be evaluated theoretically using the classical Landau model [10]. In the context of this model, the free energy density of a chiral S_C^* liquid crystal in the vicinity of S_C^*–S_A transition is written as [7–8, 10].

$$g = \tfrac{1}{2}A\theta^2 + \tfrac{1}{4}B\theta^4 - q\Lambda\theta^2 + \tfrac{1}{2}K_3\theta^2 q^2 + \tfrac{1}{2}\varepsilon^{-1}P_s^2 - C\theta P_s - \mu q\theta P_s + \ldots, \tag{10}$$

where ε is a generalized susceptibility, K_3 is the elastic modulus, Λ is the coefficient of the Lifshitz invariant term responsible for the helicoidal structure and μ and C are coefficients of the flexoelectric and piezoelectric coupling between the tilt angle θ and the polarization. A goes to zero at the 'unrenormalized' transition temperature T_0 for the FLC, i.e. $A \propto (T - T_0)$; the other constants are temperature-independents. Here it has been assumed that the tilt angle θ is relatively small (i.e. $\sim 10°$).

Now suppose that the tilt angle θ is known (θ can also be evaluated from the Landau model [7, 8]) and considering expression for q [7]

$$q = \frac{1}{K_3}\left(\Lambda + \mu\frac{P_s}{\theta}\right) = \frac{1}{K_3}(\Lambda + \mu\tilde{\varepsilon}\tilde{C}), \tag{11}$$

we have for the quantities in the right-hand side of equation (9),

$$P_s = \tilde{\varepsilon}\tilde{C}\theta, \tag{12}$$

$$\Delta\varepsilon_G = \frac{1}{2(K_3 - \varepsilon\mu^2)\varepsilon_0}\left(\frac{P_s}{q\theta}\right)^2 = \frac{K_3\tilde{\varepsilon}}{2\varepsilon\varepsilon_0}\left(\frac{\tilde{C}\tilde{\varepsilon}}{\Lambda + \mu\tilde{C}\tilde{\varepsilon}}\right)^2, \tag{13}$$

$$\tau_G = \frac{\gamma_G}{q^2(K_3 - \varepsilon\mu^2)} = \frac{K_3\tilde{\varepsilon}\gamma_G}{2\varepsilon(\Lambda + \mu\tilde{C}\tilde{\varepsilon})^2}, \tag{14}$$

where

$$\tilde{C} = C + \Lambda\mu/K_3$$

and

$$1/\tilde{\varepsilon} = 1/\varepsilon - \mu^2/K_3$$

are the renormalized constants. Thus on substituting equations (12)–(14) into equation (9), we obtain

$$\tau = \frac{\gamma_G\theta}{\tilde{\varepsilon}\tilde{C}E} \cong \frac{\gamma}{\theta\tilde{\varepsilon}\tilde{C}E}. \tag{15}$$

Both equations (9) and (15) can be used for estimation of the switching time τ. Note that a more accurate estimation for τ may be obtained in the framework of the generalized Landau model [7, 8, 11].

The authors acknowledge the European Commission for Grant No. SC*0291 on Low Molar Mass and Polymeric Liquid Crystals awarded under the Science Stimulation Programme.

References

[1] CLARK, N. A., and LAGERWALL, S. T., 1984, *Ferroelectrics*, **59**, 25.
[2] HANDSCHY, M. A., and CLARK, N. A., 1984, *Ferroelectrics*, **59**, 69.
[3] AMAYA, P. G., HANDSCHY, M. A., and CLARK, N. A., 1984, *Opt. Engng*, **23**, 261.
[4] CLARK, N. A., and LAGERWALL, S. T., 1980, *Appl. Phys. Lett.*, **36**, 899.
[5] CLARK, N. A., and LAGERWALL, S. T., 1981, *Recent Developments in Condensed Matter Physics*, Vol. 5, edited by J. T. Devreese, L. F. Lemmens, V. E. van Doren and J. van Royen (Plenum Press), p. 309.
[6] ESCHER, C., GEELHAAR, T., and BÖHM, E., 1988, *Liq. Crystals*, **3**, 469.
[7] LEVSTIK, A., CARLSSON, T., FILIPIČ, C., LEVSTIK, I., and ŽEKŠ, B., 1987, *Phys. Rev.* A, **35**, 3527.
[8] CARLSSON, T., ŽEKŠ, B., FILIPIČ, C., and LEVSTIK, A., 1990, *Phys. Rev.* A, **42**, 877.
[9] VALLERIEN, S. U., KREMER, F., KAPITZA, H., and ZENTEL, R., 1989, *Physics Lett.* A, **138**, 219.
[10] PIKIN, S. A., and UNDELBOM, V. L., 1987, *Soviet Phys. Usp.*, **21**, 487.
[11] COSTELLO, P., KALMYKOV, YU. P., and VIJ, J. K., 1992, *Phys. Rev.* A, **46**, 4852.