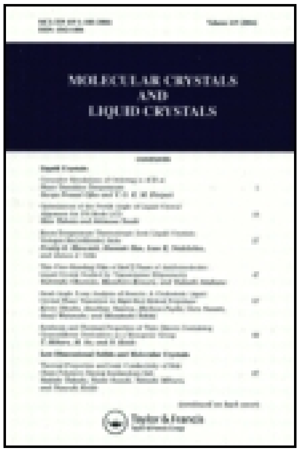

Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl17

On the Polarization Reversal of the Surfacestabilized Ferroelectric Liquid Crystal

S. A. Pikin [a]

[a] Institute of Crystallography, Moscow, USSR

Version of record first published: 20 Apr 2011.

To cite this article: S. A. Pikin (1990): On the Polarization Reversal of the Surfacestabilized Ferroelectric Liquid Crystal, Molecular Crystals and Liquid Crystals Incorporating Nonlinear Optics, 179:1, 201-206

To link to this article: http://dx.doi.org/10.1080/00268949008055370

Mol. Cryst. Liq. Cryst., 1990, Vol. 179, pp. 201–206
Reprints available directly from the publisher
Photocopying permitted by license only

Printed in the United States of America

ON THE POLARIZATION REVERSAL OF THE SURFACE-STABILIZED FERROELECTRIC LIQUID CRYSTAL

S.A.PIKIN
Institute of Crystallography, Moscow, USSR

Abstract Analytic solution describing the spread of a solitary kink through the ferroelectric smectic C film is discussed.

INTRODUCTION

The polarisation reversal in thin films of the ferroelectric smectic C liquid crystal stabilized by a surface is of great interest because of the creation of the new type of displays.[1-3] In particular the mechanism of the polarization reversal under existing conditions of work of such films is not clear yet. Parallel with numerical calculations[4-6] one should find some exact solutions or some approximate solutions with definite accuracy to make qualitative conclusions about the course of these processes. The analytic solution describing the spreading of a solitary kink through the film is found and the conditions of existence of approximate solutions are discussed in present paper.

KINK SOLUTION OF THE NONLINEAR PROBLEM

In general case the equation of director motion for the azimuth angle $\varphi(y,t)$ can be written in the form

$$PE \sin\varphi + \frac{1}{2}\Gamma \sin 2\varphi + g\theta^2 \frac{\partial^2\varphi}{\partial y^2} = \gamma\theta \frac{\partial\varphi}{\partial t} \qquad (1)$$

where P is the spontaneous polarization, E is the external electric field, g is the elastic constant, γ is the viscosity coefficient. The magnitude $\Gamma = \Gamma_o + \varepsilon_a(E\theta)^2$ characterises the anisotropy energy conditioned by anisotropic dypole-dypole interactions (Γ_o) and by the ordinary dielectric anisotropy ε_a. The parameter Γ_o must be proportional to the magnitude $(\mu\theta)^2$, where θ is the polar angle, μ is the piezoelectric constant, $\mu = (P/\theta)$. The physical meaning of the anisotropy Γ_o consists in the fact that the polarization fluctuations result in the Coulomb interaction of polarizable charges which hinders the development of these fluctuations. The preferential direction of the spontaneous polarization in a cell can be given by external influences and boundary conditions, the direction can be fixed due to the existence of free charge carriers in a film. The preferential orientation $\varphi = \pi/2$ in a cell corresponds to the positive anisotropy ($\Gamma_o > 0$), the orientations $\varphi = 0$ and $\varphi = \pi$ correspond to the negative anisotropy ($\Gamma_o < 0$).

By introducing the dimensionless variables $\tilde{y} = y/d$ and $\tilde{t} = gt/\gamma d^2$, where d is the cell thickness, one can rewrite the equation (1) in the form

$$\alpha \sin\varphi - \beta\theta \sin 2\varphi + \theta\varphi'' = \dot{\varphi} \qquad (2)$$

where

$$\alpha = \frac{PEd^2}{g\theta}, \quad \beta = -\frac{\Gamma d^2}{2g\theta^2}, \quad \varphi'' = \frac{\partial^2\varphi}{\partial\tilde{y}^2}, \quad \dot{\varphi} = \frac{\partial\varphi}{\partial\tilde{t}} .$$

The equation (2) has the exact solutions

$$\varphi = \pm \operatorname{arctg} \frac{2}{\exp(\sqrt{\beta}\,(\tilde{y}-\tilde{y}_o) - \alpha\tilde{t}) - \exp(-\sqrt{\beta}\,(\tilde{y}-\tilde{y}_o) + \alpha\tilde{t})} \qquad (3a)$$

$$\varphi = \pm \operatorname{arctg} \frac{2}{\exp(-\sqrt{\beta}\,(\tilde{y}-\tilde{y}_o) - \alpha\tilde{t}) - \exp(\sqrt{\beta}\,(\tilde{y}-\tilde{y}_o) + \alpha\tilde{t})} \qquad (3b)$$

which answer the boundary conditions

$$|\varphi| \to 0 \text{ or } |\varphi| \to \pi \text{ at } |\pm\sqrt{\beta}\,\tilde{y} - \alpha\tilde{t}| \to \infty \qquad (4)$$

The solutions (3a) and (3b) describe the solitary kinks of the function $\varphi(y,t)$ which are spreading along the y-axis and in the reverse direction, correspondingly, with the velocity

$$v = \frac{\alpha}{\sqrt{\beta}} = \sqrt{2}\ PEd(-g\Gamma)^{-1/2} \tag{5}$$

The velocity (5) has the physical meaning at the negative anisotropy $\Gamma < 0$.

APPROXIMATE SOLUTIONS

In practical situation the boundary conditions for the film with a finite thickness take the form

$$Q \sin \varphi_s = g\,\theta^2 \left(\frac{\partial \varphi}{\partial y}\right)_s \tag{6}$$

Taking into account the relation

$$\sin \varphi = ch^{-1}[\pm \sqrt{\beta}\,(\tilde{y} - \tilde{y}_\bullet) - \alpha \tilde{t}] = \pm \frac{1}{\sqrt{\beta}} \varphi'$$

one can rewrite the equation (6) in the form

$$(Q \pm \sqrt{\beta}\,\frac{g\theta^2}{d})\,ch^{-1}[\pm \sqrt{\beta}\,(\tilde{y}_s - \tilde{y}_\bullet) - \alpha \tilde{t}] = 0.$$

Thus the condition (4) is fulfilled approximately at $\alpha\tilde{t} >> 1$ and $\beta >> 1$ only. At the equality

$$Q \pm (-\Gamma g\,\theta^2/2)^{1/2} = 0 \tag{7}$$

the solutions (3a) and (3b), correspondingly, satisfy the equation (6) everywhere on the y-axis. In the absence of the equality (7) the solutions (3) can have the following meaning: near one of cell surfaces, by chance, the orientational perturbation of the kink type shapes and then it is spreading along the y axis. The width of such kink is about the magnitude

$d/\sqrt{\beta}$, the time of its formation is, for example, larger than $t_o \sim (\gamma d^2/g\alpha)$. In the time interval $\frac{d}{v} > t >> t_o$ the boundary conditions (4) for the solutions (3) are fulfilled to within a exponentially small value.

If the parameter of polar surface anchoring Q is positive, the derivative φ'_s in the boundary conditions (6) must be positive. In that case the condition (7) can be fulfilled for the solutions (3b) ($+\pi$ - kink) and (3a) ($-\pi$-kink) which correspond to the motion of $+\pi$-kink from the boundary $\tilde{y} = 1$ towards the boundary $\tilde{y} = 0$ and to the motion of $-\pi$-kink from the boundary $\tilde{y} = 0$ towards the boundary $\tilde{y} = 1$ (see Fig.1).

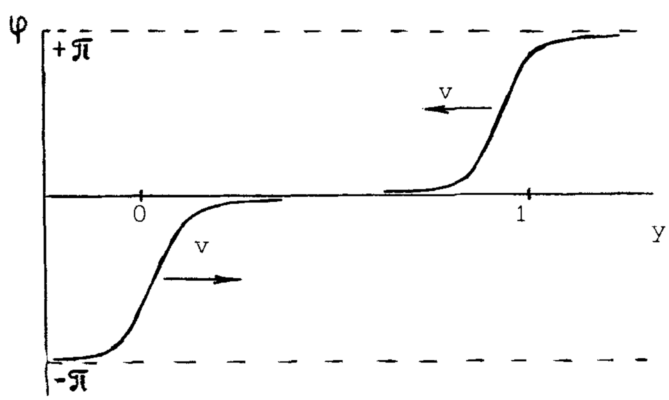

FIGURE 1. $\pm\pi$ - kinks with positive derivatives φ'_s.

If the parameter Q is negative then the condition (7) can be fulfilled for the solutions (3a) ($-\pi$ - kink) and (3b) ($+\pi$ - kink) which correspond to the motion of $-\pi$ - kink from the boundary $\tilde{y} = 0$ towards the boundary $\tilde{y} = 1$ and to the motion of $+\pi$ - kink from the boundary $\tilde{y} = 1$ towards the boundary $\tilde{y} = 0$ (see Fig.2). The velocity of such kink motion is determined by the expression (5). If the $+\pi$ - kink (3a) arises by accident near the boundary $\tilde{y} = 0$ that corresponds to the negative derivative φ'_s then at $Q > 0$ this kink can not move towards the boundary $\tilde{y} = 1$ because such solution

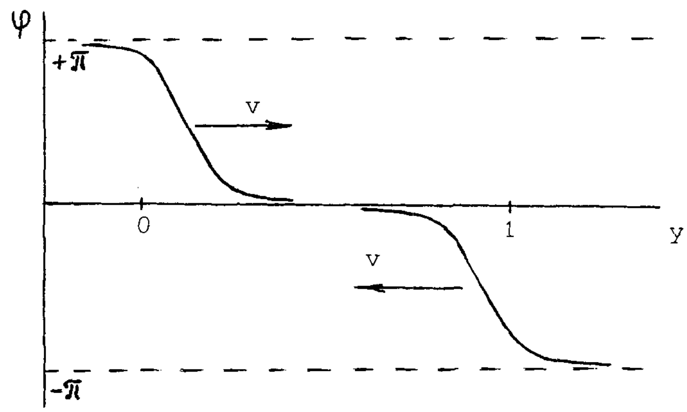

FIGURE 2. $\pm\pi$ - kinks with negative derivatives φ'_s.

does not answer the boundary conditions (6). In that case the primary perturbation (near the boundary $\tilde{y} = 0$) must spread deep into the smectic layer by the diffusion manner.

The time $t^* \sim (\sqrt{\beta}\, d/\alpha)$ is the characteristic time of kink motion across the cell, it depends on the material constants and the external field in the following manner:

$$t^* \sim \frac{(-g\Gamma)^{1/2}}{P\,E} \sim \frac{\sqrt{g}}{PE}\left(-\frac{\Gamma_o}{\theta^2} - \varepsilon_a E^2\right)^{1/2} \qquad (8)$$

Thus, under the action of strong external field the polarization reversal time stops to depend on the field E and is of the order of $t^* \sim \sqrt{g\,|\varepsilon_a|}\,/\mu \gg t_o \sim \gamma/\mu E$. In minor external fields the ratio t_o/t^* is of the order of $\gamma\theta(g\,|\Gamma_o|)^{-1/2}$, i.e. the polarization reversal time is defined by the time of kink nucleation t_o if $\gamma\theta > (g\,|\Gamma_o|)^{1/2}$.

CONCLUSIONS

The problem under consideration is spatially one-dimensional. Actually the polarization reversal problem is three-dimensional. The orientational perturbations can arise locally on film boundaries and spread in depth of film and in the plane of film. Correspondingly, the velocity of the total polarization reversal is defined by the smallest velocity of various processes, the number of centres of the kink nucleation, the interaction of solitary perturbations and other factors. This problem is substantially nonlinear, it calls for a special consideration by corresponding methods of solution. Such work is in progress.

REFERENCES

1. J.M.Geary, SID 1985 Digest of Papers(1985), p.128.
2. M.Isogai, K.Kondo, T.Kitamura, A.Mukoh, Y.Nagae, H.Kawakamu, Proc. of the 6th Int.Displ.Res.Conf."Japan Display'86" (Tokyo, 1986), p.472.
3. S.Matsumoto, A.Mirayama, Y.Kinoshita, H.Hirai, M.Ishikawa, S.Kamagami, SID 1988 Digest of Papers, (1988), p.41.
4. M.Isogai, K.Kondo, Sh.Nonaka, M.Odamura, A.Mukoh, Proc. of the 1985 Int.Displ.Res.Conf. (1985), p.228.
5. Sh.Nonaka, K.Ito, M.Isogai, M.Odamura, Jap.J.Appl.Phys. 26, 1609 (1987).
6. T.Tsuchiya, H.Takezoe, A.Fukuda, Jap.J.Appl.Phys.25, L-27 (1986).