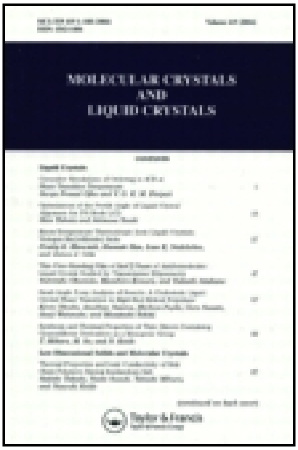


Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

EFFECT OF AZIMUTHAL SURFACE LAYER ANCHORING ON FIELD-INDUCED LAYER REORIENTATION IN A SHORT PITCH FERROELECTRIC LIQUID CRYSTAL

Wan Soo Kim [b c] , Gwangseo Park [b] & Sin-Doo Lee [a]

[a] School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul, Korea

[b] Department of Physics, Sogang University, C.P.O. Box 1142, Seoul, Korea

[c] LCD R & D Center, LG. Philips LCD, 533, Anyang, Kyonggi, Korea

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 366, pp. 557-564
Reprints available directly from the publisher
Photocopying permitted by license only

Effect of Azimuthal Surface Layer Anchoring on Field-Induced Layer Reorientation in a Short Pitch Ferroelectric Liquid Crystal

WAN SOO KIM[bc], GWANGSEO PARK[b] and SIN-DOO LEE[a]

[a]*School of Electrical Engineering, Seoul National University, Kwanak P. O. Box 34, Seoul, Korea,* [b]*Department of Physics, Sogang University, C.P.O. Box 1142, Seoul, Korea and* [c]*LCD R & D Center, LG. Philips LCD, 533, Anyang, Kyonggi, Korea*

The concept of the azimuthal surface layer anchoring (ASLA) is introduced to describe the field-induced layer reorientation in a short pitch ferroelectric liquid crystal (FLC). It was found that for the larger ASLA, the smaller layer reorientation occurs and saturates in the high field regime, especially near both surfaces. The ASLA tends to renormalize the surface interactions which produce the asymmetric director switching. It is suggested that the ASLA acts as a hindered restoring force for the layer reorientation.

Keywords: short pitch ferroelectric liquid crystal; field-induced layer reorientation; azimuthal surface layer anchoring

INTRODUCTION

The control of the layer alignment in the ferroelectric liquid crystals

(FLCs) is of great importance since the orientation and field-induced reorientation[1-2] of the layer influence decisively on the uniformity and stability of the alignment of FLCs. Particularly, the layer alignment in short pitch FLCs plays a critical role on the deformed helix (DH) FLCs[3] because it determines the intrinsic analog gray scale capability. It has been reported that the in-plane layer reorientation can be induced by an asymmetric electric field. However, a complete understanding of the layer reorientation has not been given so far.

The nature of interactions between the FLC molecules (and/or layers) and the aligning surface is expected to affect the molecular and layer orientation and reorientation. For understanding the molecular and layer reorientation under an external electric field, the ferroelectric polar and non-polar surface interactions[4], and the in-plane surface anchoring[5] has been previously introduced. Moreover, the formation and the out-of-plane stability of the bookshelf or vertical chevron layer are described in terms of the zenithal surface layer anchoring, for instance, the surface anchoring of the Sm A layer[6] or the chevron layer[7]. However, the concept of the azimuthal surface layer anchoring (ASLA) associated with the in-plane stability of the layer such as the field-induced in-plane reorientation of the layer has not been fully studied yet.

In this paper, we describe the effect of ASLA on the layer reorientation in a short pitch FLC. We present experimental results for the dynamic behavior of the layer reorientation together with numerical simulations.

EXPERIMENTALS

The FLC material used in this study was FLC10817 (ROLIC Ltd.). The material has the phase sequence as follows : I - 64.5 °C - N* - 62.4 °C - Sm C*. The material parameters at 25°C are the spontaneous polarization (P_s) = 115 nC/cm^2, the natural helical pitch (p) in Sm C* ≤ 0.2 μm, and the molecular tilt angle (θ) = 34.4°. Polyimide for low surface pretilt (1 ~ 2°) was coated on the glass substrates. The substrates were unidirectionally rubbed for homogeneous alignment. The prepared substrates were assembled using spacer of 3.0 μm thickness. The LC was filled into the prepared cell in the isotropic phase.

The filled cell was treated with a square-wave voltage of 10 V_{pp} at the frequency of 30 Hz for about 5 minutes near the N* - Sm C* phase transition to eliminate the multi-fold degeneration of the layer normal (***k***). The electric-field-treated (EFT) cell was then cooled slowly down to the room temperature. For studying the field-induced layer reorientation, a unipolar square voltage of V = 0 ~ 100 V_{pp} at the frequency of f = 1.0 ~ 30 Hz was applied to the aligned LC cell. The texture observations were performed with an optical polarizing microscope (Nikon, OPTIPHOT2-POL).

DESCRIPTION OF LAYER REORIENTATION

Figure 1 shows a schematic diagram of the DH-FLC cell and the geometrical configuration of the layer reorientation. The symbol Ω_y represents the rotation of the layer displacement about the y-axis. The vector, $\boldsymbol{k_o}$ and $\boldsymbol{k}$, are the layer normals before and after the layer reorientation, respectively. In fact, the total distortions of the Sm C* LC consist of the $\boldsymbol{c}$ director distortions for fixed layer, the layer distortions, the cross- coupling terms, and the chiral terms[12]. However, the terms associated with the variations of the layer displacement can be independently considered to describe the layer reorientation under an asymmetric external electric field.

Under the assumption of non-zero variations of Ω_y about the y-axis and no rotation of the layer displacement about the x-axis, Ω_y-dependent term in the bulk elastic free energy is given by $f^{elas} = (A/2)(\partial\Omega_y/\partial y)^2$ where A is the elastic constant[12]. The coupling between the spontaneous polarization and the electric field, which exerts the torque on the layer and induces the layer reorientation in the rubbed cells, is given by the ferroelectric free energy density, $f_p = P_s E\ \xi_L \cos(\Omega_y - \theta)$, with the coupling constant ξ_L.

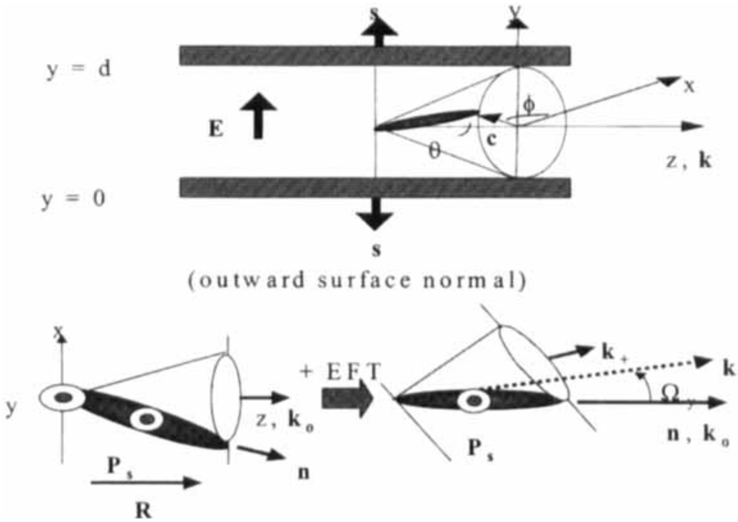


FIGURE 1 A schematic diagram of the DH-FLC cell and the geometrical configuration of the layer reorientation.

The azimuthal surface layer anchoring energy on both surfaces can be written as follows.

$$f_L^{anch} = -\gamma_L \cos^2 \Omega_y(0) - \gamma_L \cos^2 \Omega_y(d), \tag{1}$$

where γ_L is the coefficient of the azimuthal surface layer anchoring.

The total layer free energy of the system is then given as

$$F_L = \int_0^d \left(f^{elas} + f_p\right)dy + f_L^{anch} = \int_0^d f_L dy + g_L, \tag{2}$$

where f_L and g_L are the bulk and surface terms of the total layer free energy density, respectively. The Euler-Lagrange equation with two boundary conditions (BCs) can be rewritten in terms of the dimensionless quantities (y/d) of the coordinates (y) as follows,

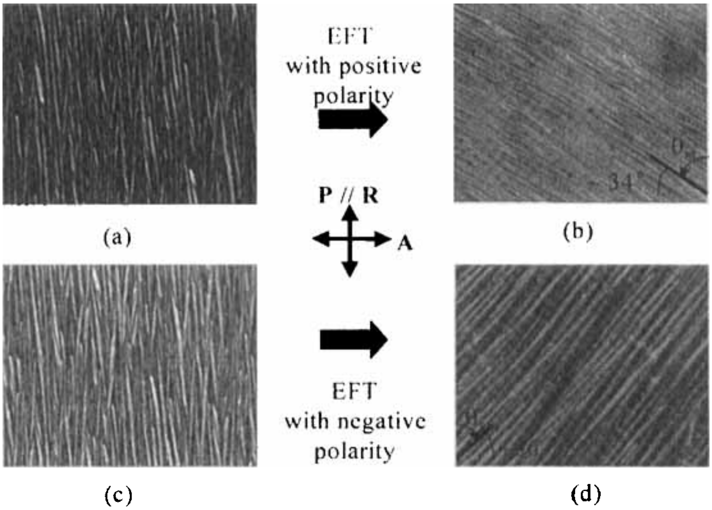


FIGURE 2 The polarizing micrographs showing the alignment textures before and after the application of the electric field (AET or EFT): (a) before AET, (b) after AET with positive polarity (80 V_p at 0.1 Hz at 53°C), (c) before AET, and (d) after AET with negative polarity (80 V_p at 0.1 Hz at 53 °C).

$$\Omega_y'' - \left(\frac{E}{E_c}\right)\sin(\Omega_y - \theta) = 0, \tag{3}$$

$$\Omega_y'(0) - \gamma_L' \sin\Omega_y(0)\cos\Omega_y(0) = 0, \tag{4}$$

$$\Omega_y'(1) + \gamma_L' \sin\Omega_y(1)\cos\Omega_y(1) \tag{5}$$

where $\Omega_y' = d\Omega_y/dy$, $\Omega_y'' = d^2\Omega_y/dy^2$, $E_c = Ad^2/ |P_s|\ \xi_L$, and $\gamma_L' = 2\gamma_L/Ad$. For obtaining numerical solutions to the above equations with BCs, we used both the finite difference method and the generalized Newton Raphson method.

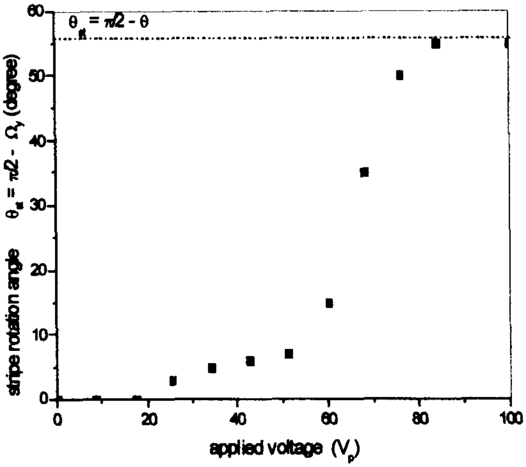
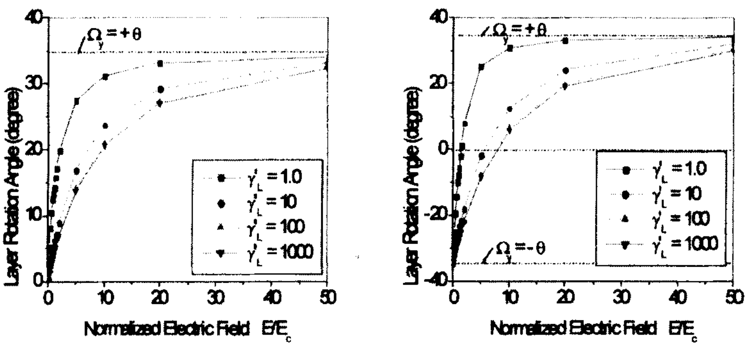


FIGURE 3 The dependence of the field-induced rotation angle θ_{st} of the stripe direction to ***R*** under a unipolar square-wave voltage at 1.0 Hz.

RESULT AND DISCUSSION

Figure 2 shows the polarizing micrographs of the textures before and after AET or EFT in FLC10817. Before AET, the stripe patterned textures (SPTs) were shown in Figs. 2(a) and 2(c) which correspond to the horizontal chevron layer structures[8]. After the application of a unipolar square-wave voltage of 80 V_{pp} at the frequency of 0.1 Hz at 53°C, SPT was rotated to the rubbing direction (***R***) as shown in Figs. 2(b) and 2(d). The field-induced rotation angle, θ_{st}, of the stripe direction to ***R*** becomes saturated at ± (π/2 - θ). The direction of SPT depends on the polarity of the applied voltage as shown in Figs. 2(b) and 2(d). Note that the field-induced rotation of SPT exhibits a reversible and temperature-dependent dynamic response. Furthermore, the dynamic response depends on the frequency and the magnitude of the applied electric field.



(a) (b)

FIGURE 4 The calculated results for the layer reorientation angle as a function of the scaled electric field: (a) θ and (b) 2θ on the mid-plane ($y/d = 0.5$).

Figure 3 shows the dependence of the layer reorientaion angle θ_{st} on the magnitude of the unipolar square-wave voltage at 1.0 Hz. There exists a certain threshold at about 20 V_{pp}. Above the threshold, the stripe rotation angle sharply increases and finally approaches a saturated value (~ 55°) which corresponds to $\pi/2$ - θ. This implies the energy corresponding to the threshold is equivalent to the surface layer anchoring energy. Figs. 4(a) and 4(b) show the calculated results for the layer rotation angle as a function of the scaled electric field. The rotation angle was calculated on the mid-plane (y/d = 0.5) of the cell. There exists θ rotation in a FLC with the Sm A phase and 2θ rotation in a FLC with no Sm A phase. For larger azimuthal surface layer anchoring, smaller layer rotation is obtained. The simulation results obtained within our model are in reasonable agreement with the experimental results. It may be then concluded that the azimuthal surface layer anchoring tends to renormalize the surface interactions which produce the asymmetric director switching. This type of layer anchoring behaves as a driving force for the layer reorientation, which in turn as the resistant hindrance for the layer reorientation.

CONCLUDING REMARKS

We have investigated the effect of the azimuthal surface layer anchoring on the layer reorientation induced by an asymmetric electric field in a short pitch FLC. It was found that there exists a certain threshold of the voltage for the layer reorientation. Moreover, for larger azimuthal surface layer anchoring, the smaller layer reorientation is induced, especially near the surfaces. The experimental results agree reasonably well with our simulation results.

Acknowledgments

This work was supported in part by Ministry of Education of Korea through Brain Korea 21 Project.

References

[1] J.S. Patel and J.W. Goodby, *J. Appl. Phys.* **59**, 2355 (1986).
[2] J.S. Patel, S.-D. Lee, and J.W. Goodby, *Phys. Rev. A* **40**. 2854 (1989).
[3] A. Beresnev, L.M. Blinov and D.I. Dergachev, *Ferroelectrics* **85**, 173 (1988).
[4] M.A. Handschy, N.A. Clark, and S.T. Lagerwall, *Phy. Rev. Lett.* **51**, 471 (1983).
[5] P. Schiller, *Ferroelectrics*, **122**, 261 (1991).
[6] P.G. de Gennes and J. Prost, *The Physics of Liquid Crystals*(Oxford University Press, London, 1993).
[7] M. Brunet and L. Lejecek, *Liq. Crst.*, **19**, 1 (1995).
[8] J. Fünfschilling and M. Schadt, *Jpn. J. Appl. Phys.* **30**, 741 (1991).