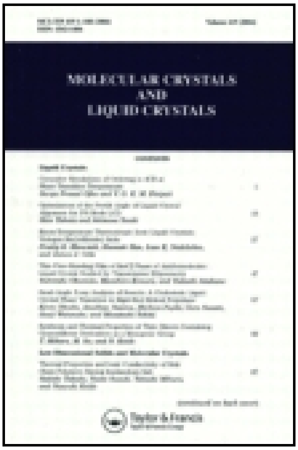

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

The Boundary Layer Displays with Nematic Liquid Crystals Based on "Flexoelectric Effects"

Taiju Takahashi [a], Makio Usui [a], Hirokazu Nishijou [a], Munehiro Kimura [a] & Tadashi Akahane [a]

[a] Department of Electrical Engineering, Faculty of Engineering, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata, 940-21, Japan

Version of record first published: 04 Oct 2006

To cite this article: Taiju Takahashi, Makio Usui, Hirokazu Nishijou, Munehiro Kimura & Tadashi Akahane (1998): The Boundary Layer Displays with Nematic Liquid Crystals Based on "Flexoelectric Effects", Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 316:1, 235-240

To link to this article: http://dx.doi.org/10.1080/10587259808044499

Mol. Cryst. Liq. Cryst., 1998, Vol. 316, pp. 235–240
Reprints available directly from the publisher
Photocopying permitted by license only

The Boundary Layer Displays with Nematic Liquid Crystals Based on "Flexoelectric Effects"

TAIJU TAKAHASHI, MAKIO USUI, HIROKAZU NISHIJOU, MUNEHIRO KIMURA, and TADASHI AKAHANE
Department of Electrical Engineering, Faculty of Engineering, Nagaoka University of Technology, 1603-1 Kamitomioka, Nagaoka, Niigata 940-21, Japan

The boundary layer display (BLD) with nematic liquid crystals (LCs) was proposed by J. Cheng *et al.* in 1982, which has a 45° twisted angle and splay distortions. BLD cells show the quasi-bistable characteristics, controlled by the sign of the applied dc voltage. They came to conclusion that the polarity of the torque in BLD cells was induced by ions. However, we assume this behavior is due to the flexoelectric effects in nematics, which is dominant over effects of ions. Simulations for BLD cells are carried out by the continuum theory with flexoelectric effects. The main factor of this phenomena can be explained as flexoelectric effects.

Keyword: nematic; flexoelectric; boundary layer; dc applied voltage

INTRODUCTION

The structure of the BLD cell with nematic LCs that is proposed by J. Cheng *et al.*[1,2,3] is illustrated in Fig. 1. It has a splay distortion and 45° twist, and the voltage is applied across the cell. Without the voltage, the boundary layer, where the director is almost parallel to the cell surface, is located at the center of the cell, as shown in Fig. 1 (a). When the dc voltage is applied, it moves to the upper or lower surface of the cell, depending on the sign of the applied dc voltage. Figure 1 (b) shows the

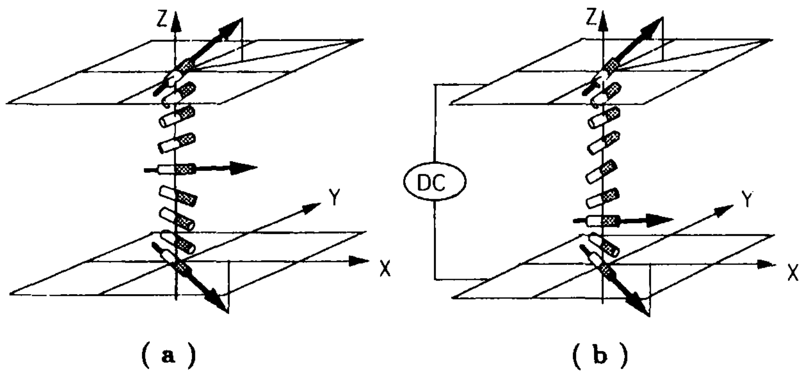

FIGURE 1 The structure of the BLD cell.

case where it moves to the lower surface. The polarized axis of each polarizer at incident side and the exit side is set along the x axis and y axis, respectively. When two types of the dc voltages that have opposite polarity but the same absolute value are applied, the different characteristics of the transmittance are observed. Furthermore, if the applied field is switched from the dc one to the ac one, the director orientation can be kept to that state, thus, the appearance of quasi-bistable switching characteristics can be achieved. It is explained by J. Cheng *et al.* [4], that this switching mechanism is due to the impurity ions. However we assumed, the polarity is induced by flexoelectric effects in nematics [5], because BLD cells have a splayed strain structure. The flexoelectric effects allows the direction of the director to be changed by the externally applied dc voltage, due to the first order coupling between the applied electric field and the polarization by the flexoelectric effect.

Then, simulated results which are carried out using continuum theory with flexoelectric effects and the corresponding experimental results are shown.

THEORY

We present a following model to calculate the field-induced director reorientation and electrooptical characteristics of such BLD cells. It is assumed that the main factor for the polarity of the driving torque is induced by the flexoelectric effect, which is dominant over effects of ions. We perform the numerical calculations using the continuum theory with flexoelectric effects, neglecting the influence of ions. The total free energy per unit area of the cell by continuum theory is described as

$$\begin{aligned} F &= \int_0^d [\frac{1}{2}\{f(\theta)(\frac{\partial\theta}{\partial z})^2 + g(\theta)(\frac{\partial\phi}{\partial z})^2 - h(\theta)(\frac{\partial V}{\partial z})^2\} \\ &+ (e_{11}+e_{33})\sin\theta\cos\theta(\frac{\partial\theta}{\partial z})(\frac{\partial V}{\partial z})]dz + f_{s0} + f_{sd}, \end{aligned} \tag{1}$$

where, θ is a polar angle of director from the cell substrate and ϕ is an azimuthal angle from the x axis, respectively. V is an electric scalar potential, e_{11} and e_{33} are flexoelectric coefficients corresponding to the splay and bend distortion, respectively, and

$$\begin{aligned} f(\theta) &= K_{11}\cos^2\theta + K_{33}\sin^2\theta, \\ g(\theta) &= \cos^2\theta(K_{22}\cos^2\theta + K_{33}\sin^2\theta), \\ h(\theta) &= \varepsilon_0(\varepsilon_p\sin^2\theta + \varepsilon_n\cos^2\theta). \end{aligned}$$

The surface anchoring energies f_{s0} and f_{sd} are described as[6],

$$\begin{aligned} f_{s0} &= \frac{1}{2}\{A_{\theta 0}\sin^2(\theta_{[0]} - \theta_0) \\ &\quad + A^*_{\phi 0}\cos^2\theta_{[0]}\sin^2(\frac{(\phi_{[0]} - \phi_0)}{2})(1 - \cos^2\theta_{[0]}\sin^2(\frac{(\phi_{[0]} - \phi_0)}{2}))\}, \\ f_{sd} &= \frac{1}{2}\{A_{\theta d}\sin^2(\theta_{[d]} - \theta_d) \\ &\quad + A^*_{\phi d}\cos^2\theta_{[d]}\sin^2(\frac{(\phi_{[d]} - \phi_d)}{2})(1 - \cos^2\theta_{[d]}\sin^2(\frac{(\phi_{[d]} - \phi_d)}{2}))\}, \end{aligned}$$

where, $\theta_{[0]\,\mathrm{or}\,[d]}$, $\phi_{[0]\,\mathrm{or}\,[d]}$ describe the actual angle of the director, and $\theta_{0\,\mathrm{or}\,d}$, $\phi_{0\,\mathrm{or}\,d}$ describe the angle of the easy axis on each surface, respectively. When the dc voltage is applied to the cell, the dielectric and the flexoelectric effect are concerned with the director reorientation, and when the applied voltage is changed to the ac voltage, the dielectric effect remains but the flexoelectric effect can not respond to the applied field if its frequency is high enough. The electrooptical characteristics (T–V curves) are calculated using Jones matrix. The characteristics of the field-induced director deformation for the static response under the dc applied voltage are calculated. After that, when the applied field is switched from dc one to ac one, the behavior of the dynamic response is calculated to investigate what state the director distribution relaxes to under the ac voltage.

RESULTS AND DISCUSSIONS

For experiments, substrates of sample cells were coated with SiO_x films to align LC molecules by the oblique evaporating method, and the pre-tilt angle was 33°. The cell was filled with a nematic mixture; E7, and the cell thickness was 6.7μm.

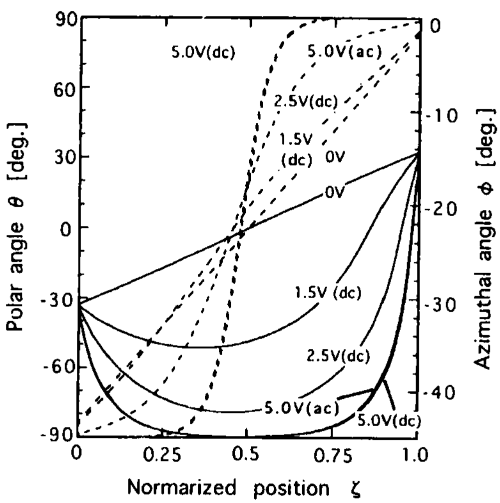

FIGURE 2 Field-induced deformation of director reorientation of the BLD cell.

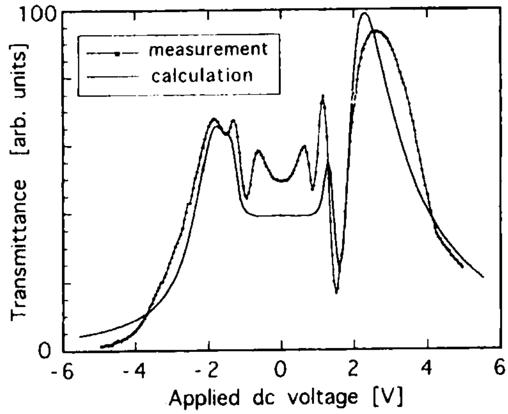

FIGURE 3 Transmittance versus applied dc voltage of the BLD cell.
(simulation and measurement)

For calculations, the material parameters of E7 were used. Anchoring coefficients $A_{\theta 0}$, $A_{\theta d}$=5×10^{-4} J/m^2 and $A^*_{\phi 0}$, $A^*_{\phi d}$=5×10^{-5} J/m^2, respectively. The sum of the flexoelectric coefficients $e_{11} + e_{33} = -10 \times 10^{-12}$ C/m (tentative value) was used. The characteristics of the director distributions are shown in Fig. 2. It is found that the boundary layer (the part of $\theta \approx 0$) moves to the upper substrate ($\zeta = 1$), as the applied dc voltage increases. The case of the electric field with the opposite sign is applied, the moving direction of that layer is also opposite, i.e., toward $\zeta = 0$. The steady state for the dynamic response under the ac applied voltage of 5 V after switched from the dc 5 V are shown in Fig. 2. The cause of the difference between those curves is whether the flexoelectric effects are present or absent, but there is little difference in calculated result with varying the flexoelectric coefficients. From those results, it seems that when the dc field is applied to the cell in which the director orientation is in the initial state without applied voltage, the moving direction of the director is determined by flexoelectric effects, after that, the director reorientation mainly depend on dielectric effects.

The example of the T–V characteristics of the measurement result and the simulated result under the dc applied voltage is shown in Fig. 3.

CONCLUSION

Simulations were carried out to investigate the behavior of the director reorientation by the continuum theory which takes the flexoelectric effects into account. The factor of driving mechanism of BLD cells was explained by the flexoelectric effects in place of the effects of ions.

It is found that the flexoelectric effect determines the moving direction of the boundary layer when the dc voltage is applied, and the dielectric effects are dominant over the flexoelectric effects, after the moving direction is once determined.

REFERENCES

[1.] J. Cheng, R. N. Thurston, G. D. Boyd and R. B. Meyer, *Appl. Phys. Lett.*, **40**, 1007 (1982)
[2.] R. B. Meyer and R. N. Thurston, *Appl. Phys. Lett.*, **43**, 342 (1983)
[3.] R. N. Thurston, G. D. Boyd and D. C. Senft, *J. Appl. Phys.*, **55**, 3846 (1984)
[4.] R. N. Thurston, J. Cheng, R. B. Meyer and G. D. Boyd, *J. Appl. Phys.*, **56**, 263 (1984)
[5.] R. B. Meyer, *Phys. Rev. Lett.*, **22**, 918 (1969)
[6.] T. Takahashi, S. Saito, T. Akahane, *Jpn. J. Appl. Phys.*, **36**, 3531 (1997)