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

Dynamic response of super-twisted nematic liquid crystal displays

Hongfei Cheng; Hongjin Gao

Online publication date: 11 November 2010

To cite this Article Cheng, Hongfei and Gao, Hongjin(2002) 'Dynamic response of super-twisted nematic liquid crystal displays', Liquid Crystals, 29: 5, 719 — 723
To link to this Article: DOI: 10.1080/02678290210129948
URL: http://dx.doi.org/10.1080/02678290210129948

LIQUID CRYSTALS, 2002, VOL. 29, NO. 5, 719–723

Taylor & Francis
Taylor & Francis Group

Dynamic response of super-twisted nematic liquid crystal displays

HONGFEI CHENG* and HONGJIN GAO
Center of Liquid Crystal Technology, Department of Chemistry,
Tsinghua University, Beijing 100084, PR China

(*Received 21 June 2001; in final form 2 January 2002; accepted 2 January 2002*)

The dynamics of super-twisted nematic (STN) liquid crystal displays was studied by detailed computer simulation. The time evolution of director configuration and velocity of flow as obtained by solving Ericksen–Leslie hydrodynamic equations. The influence of d/p value and pretilt angle on the dynamic response was also studied. A comparison was also made between twisted nematic and STN liquid crystal displays.

1. Introduction

Since Schadt and Helfrich discovered the electro-optical properties of twisted nematic (TN) liquid crystals in 1971 [1], the TN variety have found numerous applications, such as in wrist-watch, clock and low-end character displays. However the contrast ratio of these displays is limited and the viewing angle is narrow. The enormous growth in the demand for liquid crystal displays (LCDs) with large information capacities has motivated the search for alternative LCD technologies and electro-optical effects. A new electro-optical effect reported by Waters *et al.* and Scheffer *et al.* using 270° devices is known as the super-twisted nematic (STN) effect [2, 3]. The STN liquid crystal display has a steep electro-optical response suitable for high information content displays. The STN liquid crystal display has a much better image quality than a TN display multiplexed at the same level. In industry, the twist angle of the super twisted liquid crystal layer usually has the value 180°, 220° or 240° to facilitate production processing. STN displays have found wide applications in many areas such as hand-held games, personal digital assistance, and mobile phones.

Although STN LCDs have been studied carefully for their static electro-optical response, their dynamic behaviour has seldom been investigated. In the dynamic behaviour of LCDs, the flow of liquid crystal could have an important influence under certain circumstances. For example, the well known optical bounce phenomenon of the TN LCD which occurs after switching off a high applied voltage is caused by the backflow effect [4, 5].

In this article, the STN dynamics are studied by detailed computer simulation. The transient property of STN cells is obtained by solving the Ericksen–Leslie hydrodynamic equations.

*Author for correspondence,
e-mail: zxl-dch@mail.tsinghua.edu.cn

2. Description of method

The Ericksen–Leslie hydrodynamic equations are

$$\partial_t(\rho v_i) + \partial_j(\rho v_i v_j + p\delta_{i,j} - \sigma^{\mathrm{d}}_{ji} - \sigma^{\mathrm{f}}_{ji} - \sigma'_{ji}) = 0$$

$$I\mathrm{d}^2 n_i/\mathrm{d}t^2 = h_i + h'_i + \gamma n_i$$

where i and j denote x, y, or z components, ρ is the fluid density, v is the fluid velocity, p is the hydrostatic pressure, σ^{d} is the stress tensor from elastic distortion, σ^{f} is the stress tensor induced by electric and magnetic fields, σ' is the viscous stress tensor, h is the molecular field from elastic free energy, h' is the viscous molecular field, I is the rotational inertial density of the fluid, γ is a Lagrangian multiplier, and n is the unit vector of liquid crystal director. In this work, we limited the problem to the one-dimensional case; all the variables therefore depend on z and t. The boundary conditions are that, at the substrates the velocity components vanish and the directors are fixed and time-independent. The explicit expressions for the various quantities can be found in the continuum theory of Ericksen and Leslie [6, 7].

To simulate the dynamic behaviour of the STN displays, we solved the equation of Ericksen–Leslie hydrodynamic theory and then obtained the transient director distribution. The inertial terms in the equation were neglected in the simulation because their influence is very small in comparison with the viscous term. Since there are very few measurements of all the viscosity coefficients, here we use the six Leslie viscosity constants for MBBA [5, 8].

3. Results

The parameters used in the simulation are listed in the table. We assumed the STN device to have twist angle 240° and pretilt angle 5°. The liquid crystal layer had left-handed twist. The evolutions of tilt angle and twist angle after switching on the holding voltage V_{H} are

Liquid Crystals ISSN 0267-8292 print/ISSN 1366-5855 online © 2002 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/02678290210129948

Table. The parameters used in numerical computation.

Cell gap $d = 5.0\,\mu m$	$\alpha_1 = 0.0359\ g\,cm^{-1}\,s^{-1}$
$K_{11} = 1.24 \times 10^{-7}$ dyn	$\alpha_2 = -0.4283\ g\,cm^{-1}\,s^{-1}$
$K_{22} = 0.6 \times 10^{-7}$ dyn	$\alpha_3 = -0.0066\ g\,cm^{-1}\,s^{-1}$
$K_{33} = 1.71 \times 10^{-7}$ dyn	$\alpha_4 = 0.4598\ g\,cm^{-1}\,s^{-1}$
$\varepsilon_{\parallel} = 13.8$	$\alpha_5 = 0.2559\ g\,cm^{-1}\,s^{-1}$
$\varepsilon_{\perp} = 6.6$	$\alpha_6 = \alpha_2 + \alpha_3 + \alpha_5$ (Onsager's relation)

shown in figures 1 and 2, respectively. In the simulation, left-handed twist has negative value in the Cartesian coordinate, but twist angle is presented as a positive value throughout the whole paper: the same applies to d/p values. The configuration approaches the equilibrium state monotonously. It is found that after switching on the applied voltage, the tilt angle of the directors around the central part of the cell increases faster than for regions near the substrates. Since the rotation is induced by the external field, and the orientational force for polar anchoring is weaker here, the directors which are far from the substrate can be rotated more easily by the external field. The tilt angle takes about 40 ms to reach its saturated value; that is, the tilt angle is almost unchanged at 40 ms after the voltage is switched on. After the voltage is switched on, the twist angle remains almost unchanged for 20 ms. The twist angle also reaches its saturated value in about 40 ms after the voltage is switched on. The velocities of flow in the x and y directions are shown in figures 3 and 4; the x direction is in the direction of the initial liquid crystal director of the STN cell and the z direction is across the cell thickness. The STN device has very complex pattern of flow.

The evolutions of tilt angle and twist angle after switching off the holding voltage V_H are shown in figures 5 and 6. The configuration approaches the equilibrium state monotonously. The tilt angle reaches its saturated value in about 20 ms and the twist angle reaches its saturated value in about 10 ms. Their velocities of flow in the x and y directions are shown in figures 7 and 8.

Figures 9 and 10 show the middle layer tilt angle for different d/p values as a function of time after V_H is

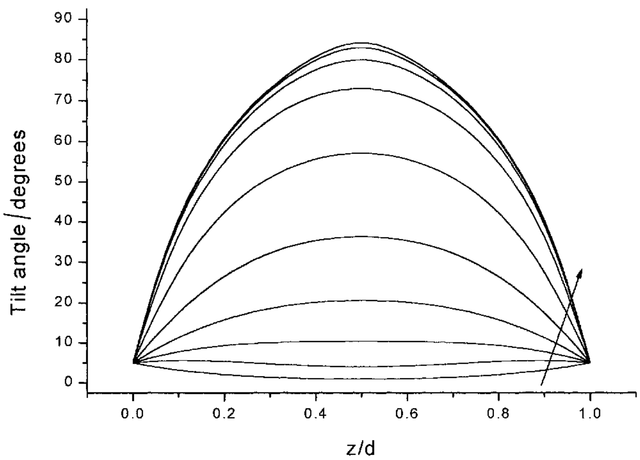

Figure 1. Time-varying tilt angle after switching on $V_H = 3$ V. The time interval between each two neighbouring curves is $\delta t = 4$ ms. d/p value is 0.55.

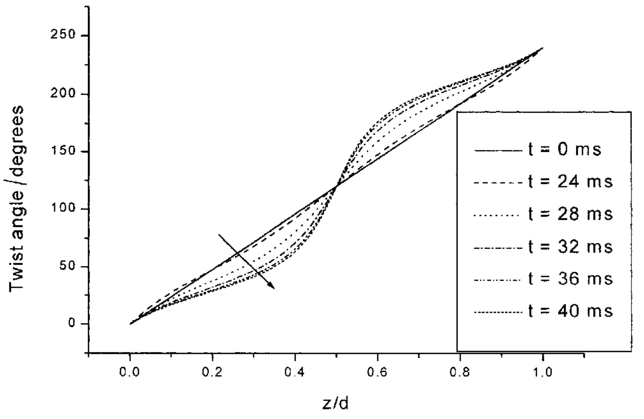

Figure 2. Time-varying twist angle after switching on $V_H = 3$ V. d/p value is 0.55.

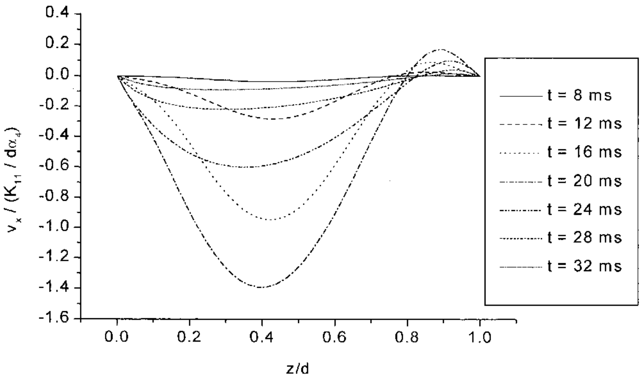

Figure 3. Space and time dependence of flow velocity component v_x after switching on $V_H = 3$ V. d/p value is 0.55.

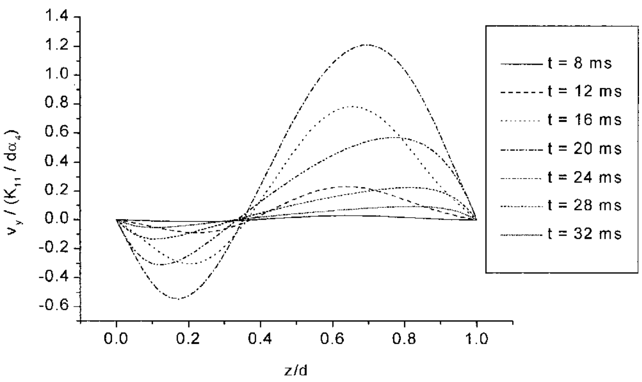

Figure 4. Space and time dependence of flow velocity component v_y after switching on $V_H = 3$ V. d/p value is 0.55.

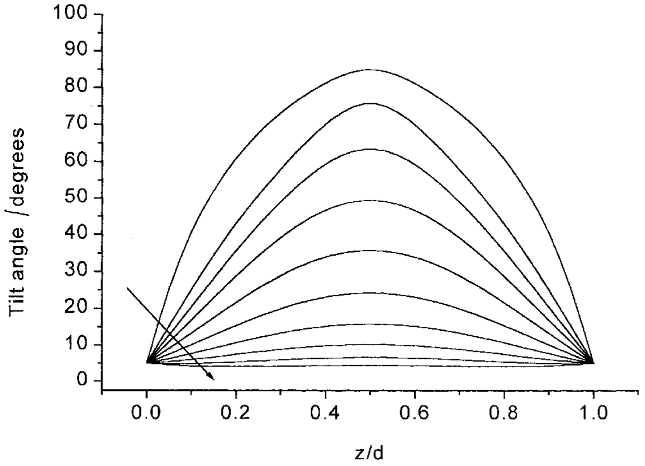

Figure 5. Time-varying tilt angle after switching off $V_H = 3$ V. The time interval between each two neighbouring curves is $\delta t = 2$ ms. d/p value is 0.55.

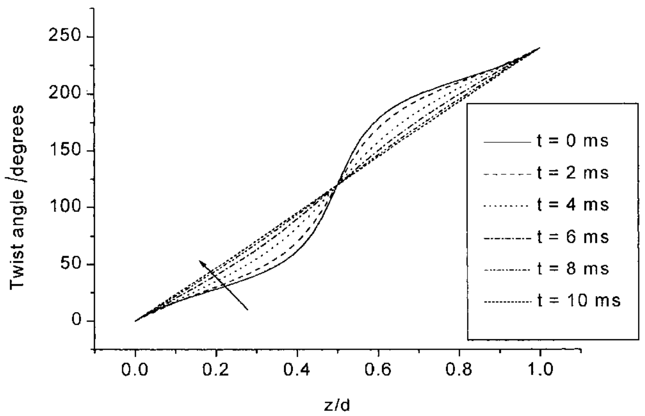

Figure 6. Time-varying twist angle after switching off $V_H = 3$ V. d/p value is 0.55.

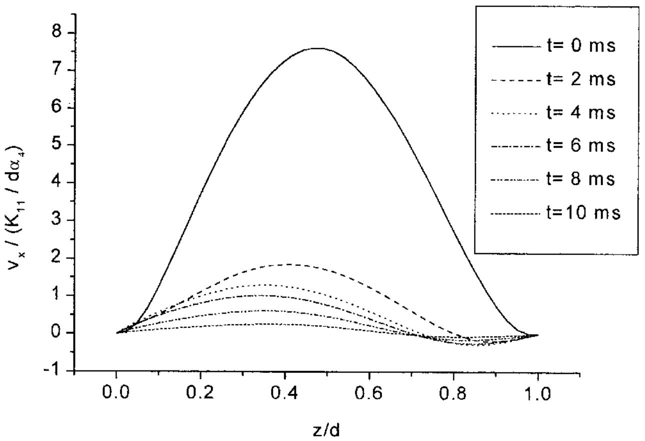

Figure 7. Space and time dependence of flow velocity component v_x after switching off $V_H = 3$ V. d/p value is 0.55.

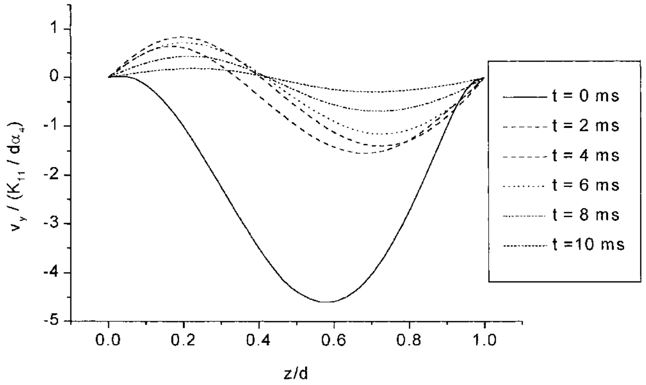

Figure 8. Space and time dependence of flow velocity component v_y after switching off $V_H = 3$ V. d/p value is 0.55.

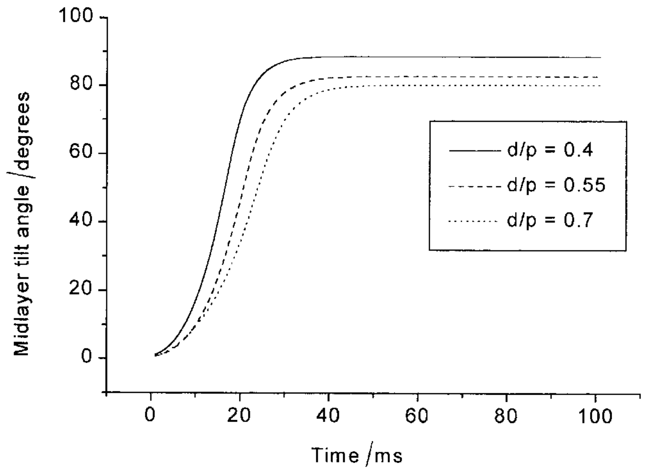

Figure 9. Time-varying middle layer tilt angle for different d/p values after switching on $V_H = 3$ V. Pretilt angle is 5°.

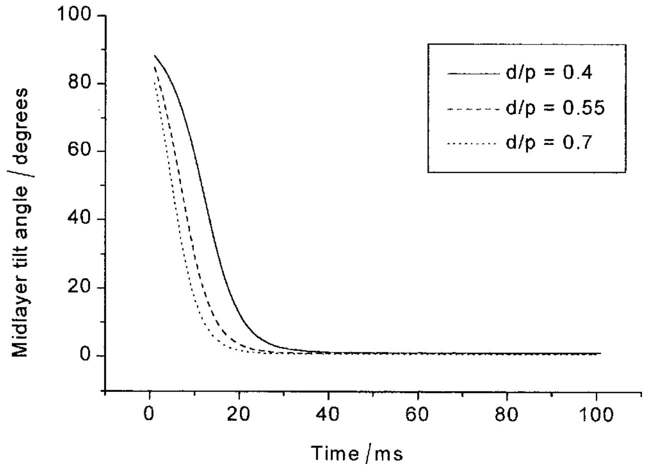

Figure 10. Time-varying middle layer tilt angle for different d/p values after switching on $V_H = 3$ V. Pretilt angle is 5°.

switched on and off, respectively. It is reasonable to use the time-varying middle layer tilt angle as a measure of dynamic response of the STN cells. The rise time T_r

is defined as the time required to reach 90% of the maximum middle layer tilt angle. The fall time T_f is defined as the time required to reach the point where the middle layer tilt is 10% of its minimum middle layer tilt angle. From figure 9, the rise time T_r increases as the d/p value increases. From figure 10, the fall time T_f decreases as the d/p value increases.

Figures 11 and 12 show the middle layer tilt angle for different pretilt angles as a function of time after V_H is suddenly switched on and off, respectively. From figure 11, the rise time T_r shortens as the pretilt angle increases. From figure 12, the fall time T_f increases as the pretilt angle increases.

The effects of d/p value and pretilt angle on the dynamic response are interesting. The response time shows a reverse trend for the voltage switched on or off as d/p value or pretilt angle increases.

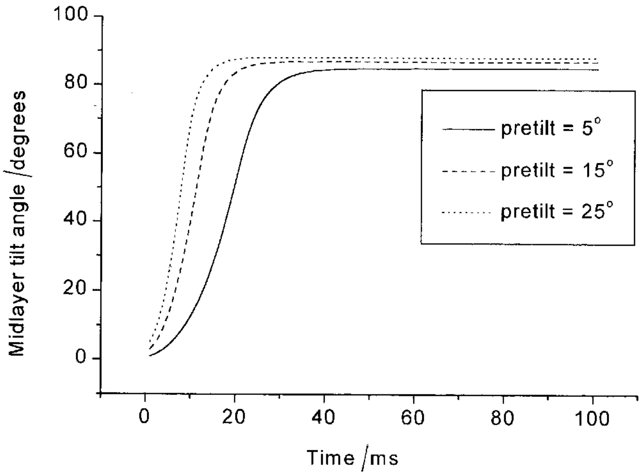

Figure 11. Time-varying middle layer tilt angle for different pretilt angles after switching on $V_H = 3$ V. d/p value is 0.55.

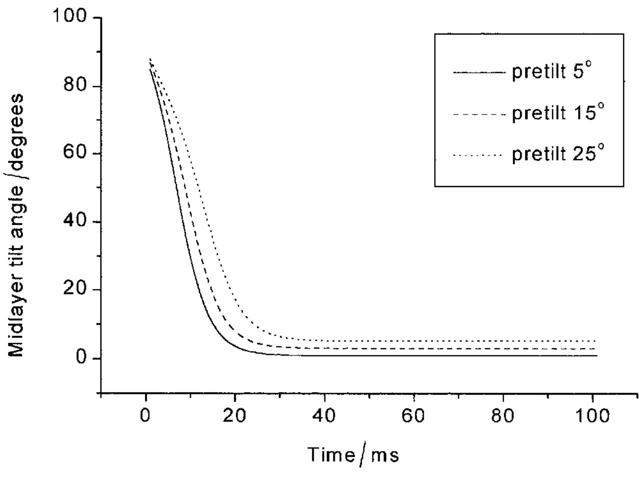

Figure 12. Time-varying middle layer tilt angle for different pretilt angles after switching off $V_H = 3$ V. d/p value is 0.55.

Figures 13 and 14 show the tilt and twist angles of a TN liquid crystal cell after V_H is suddenly switched off. The calculation was made using the same parameters as those used for the STN devices except that twist angle is 90° and pretilt angle is 2°. An abnormal twist arises in the initial few seconds after V_H is switched off. The abnormal twist means that the direction of twist changes along the z direction. The well known optical bounce is believed to be associated with the abnormal twist. Although twisted nematic cell dynamics has been studied before, the time-varying configuration has for the first time been represented in terms of tilt angle and twist angle. This representation gives a new insight into the optical bounce. The previous explanation of the optical origin of the TN cell is that directors pass the axis perpendicular to the substrate twice, causing a local decrease of the phase retardation when the tilt angle returns to 90° and then it forms the optical bounce [4, 5].

There have been no reports that STN devices exhibit the optical bounce. From our results, the direction of twist of STN devices remains the same whether the holding voltage V_H is switched off or on. The abnormal twist does not occur. Jone's matrix method was also employed to calculate transmittance as a function of time in this investigation; indeed no optical bounce was observed.

4. Conclusions

(i) We have investigated the dynamics of STN cells by solving Ericksen–Leslie hydrodynamic equations. The transient liquid crystal configuration and velocity of flow were obtained.

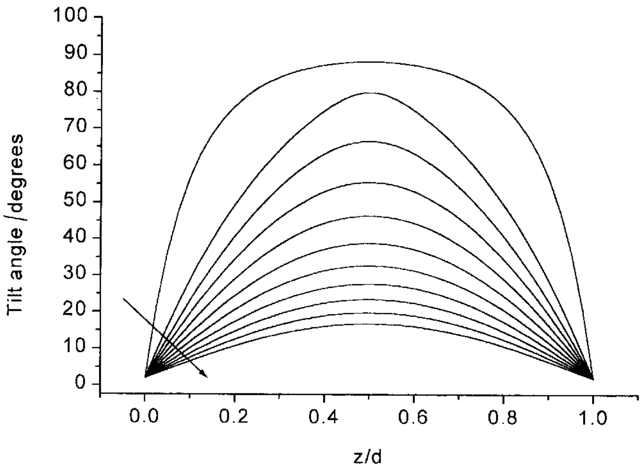

Figure 13. Time-varying tilt angle for twisted nematic cell after switching off $V_H = 5$ V. The time interval between each two neighbouring curves is $\delta t = 2$ ms.

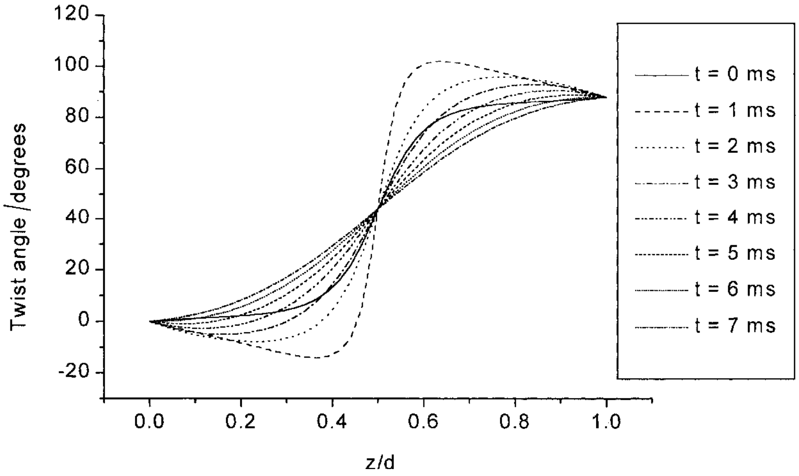

Figure 14. Time-varying twist angle for twisted nematic cell after switching off $V_H = 5$ V.

(ii) The effects of d/p value and pretilt angle on the dynamic response were investigated. The time-varying middle layer tilt angle was used to measure the dynamic response of STN cells.

(iii) The transient flow of a TN cell was also solved in comparison with an STN cell. An abnormal twist was observed for the TN cell immediately after the holding voltage was switched off. This abnormal twist was related to the optical bounce phenomenon in TN cells. The transient configuration of the STN cell approached its equilibrium state monotonously, and no optical bounce phenomenon was observed.

References

[1] Schadt, M., and Helfrich, W., 1971, *Appl. Phys. Lett.*, **18,** 127.
[2] Waters, C. M., Raynes, E. P., and Brimmell, V., 1985, *Mol. Cryst. liq. Cryst.*, **123,** 303.
[3] Scheffer, T. J., and Nehring, J., 1984, *Appl. Phys. Lett.*, **45,** 1021.
[4] Van Doorn, C. Z., 1975, *J. appl. Phys.*, **46,** 3738.
[5] Berreman, D. W., 1975, *J. appl. Phys.*, **46,** 3746.
[6] Eriksen, J. L., 1969, *Mol. Cryst. liq. Cryst.*, **7,** 153.
[7] Leslie, F. M., 1966, *Quart. J. Mech. appl. Math.*, **19,** 357.
[8] Gäwiler, C., 1971, *Phys. Lett.*, **A36,** 311.