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The Flexoelectric Behaviour of a Hypertwisted Chiral Nematic Liquid Crystal

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The flexoelectric behaviour of a hypertwisted chiral nematic bimesogenic liquid crystal is presented. Through detailed electro-optic measurements, with particular emphasis on the switching properties, we demonstrate remarkably high optical axis tilt angles. The material studied possessed a room temperature nematic phase and aligned easily on cooling under the application of a moderate electric field. Switching times of the order of 500 μs and contrast ratios of 90:1 are readily achieved. The tilt angles, measured using the rotating analyser technique, were found to be practically temperature independent and linear with the applied field. Tilt angles of 22.5° were obtained with moderate applied fields of 9.4 V/μm whilst fields of 25 V/μm yielded tilt angles of 45°. We believe these are the highest tilt angles ever recorded for such fields.

Keywords: Flexoelectric; Tilt Angle; Chiral Nematic; Bimesogen; Liquid Crystal; Hypertwist

INTRODUCTION

Nematic liquid crystals have been utilised in display devices for many years. The electro-optical effects have been the subject of many

detailed investigations and are well understood. One of the main limitations of these displays is the optical response time to the applied electric field. Recently, much interest has been shown in a new, fast electro-optical effect observed in both the nematic and chiral nematic liquid crystalline phases. The flexoelectro-optic effect[1,2] has great potential for use in display applications and optical modulators due to the short optical response times and temperature independent optic axis tilt angles which are linear in the applied field. In this paper we are solely concerned with the flexoelectro-optic effect occurring in highly twisted nematic flexoelectric liquid crystal bimesogens[3].

The flexoelectro-optic effect is readily observed in parallel plate cells in which the helix axis of a hypertwisted chiral nematic is uniformly aligned parallel to the glass cell plates, the so called uniformly lying helix (ULH) texture, a schematic of which is given in Figure 1.

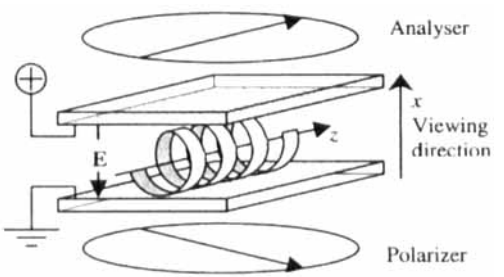

FIGURE 1 The cell geometry required in order to view the flexoelectro-optic effect.

With no external field applied this configuration behaves as a uniaxial birefringent material with its optic axis parallel to the helix axis, see Figure 2a. An electric field applied across the cell plates, normal to the helix axis, causes a rotation of the director plane, see Figure 2b. This distortion of the helix results in a periodic splay-bend deformation perpendicular to the macroscopic optic axis. The net result of the applied field is that the system behaves as if the optic axis is rotated in a plane parallel to the glass plates, as was first shown by Meyer and Patel in 1987 [2].

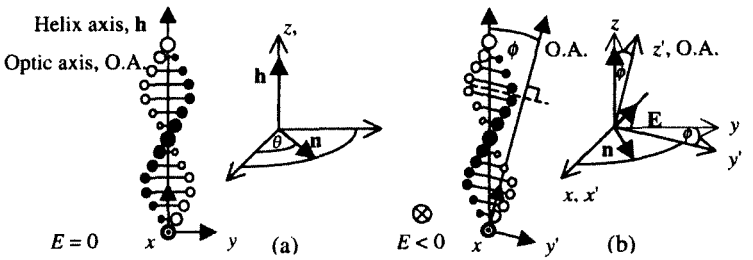

FIGURE 2 (a) An undisturbed chiral nematic material with right-handed helicity, the directors are confined to the xy-plane, orthogonal to the helix and optic axes. (b) The effect of an electric field applied along the $-x$ direction: the director plane and optic axis are rotated by an angle $+\phi$ about the x-axis.

This affect arises due to flexoelectric coupling, which is linear in the electric field and hence results in a linear electro-optic response. The angle of rotation, ϕ, is given by the relationship [2]:

$$\tan\phi = \frac{\bar{e}}{k\kappa}E \qquad (1)$$

where $\bar{e}$ is an effective flexoelectric coefficient $\bar{e} = (e_s + e_b)/2$
κ is an effective elastic constant $\kappa = (\kappa_{11} + \kappa_{33})/2$
k is the pitch length

Hence for small angles, where $\phi \approx \tan(\phi)$, the tilt angle is proportional to E. The magnitude of the tilt angle is also approximately temperature independent, providing the pitch does not change significantly with temperature. Equation (1) then gives us ϕ proportional to $\bar{e} / \kappa$, where both $\bar{e}$ and κ vary with the square of the order parameter [4,5], S, consequently $\bar{e} / \kappa$ is constant.

Flexoelectric switching has short response times [6], τ, often in the microsecond range.

$$\tau = \frac{\gamma_1}{k^2\kappa} \qquad (2)$$

where γ_1 is the effective viscosity related to the helix distortion

MATERIALS

A series of nematic bimesogenic liquid crystals have been synthesised, the generic structure of which is shown in Figure 3. Where X, Y, Z

are functional Halogenic groups and n is the number of carbon atoms in the spacer unit.

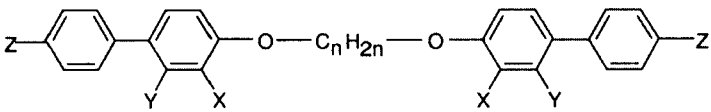

FIGURE 3 The generic structure of the hypertwisted nematic material studied.

The phase sequence was determined by optical microscopy, the temperature being controlled by a Linkam TP91 hotstage and controller. On cooling from the isotropic phase, with no external field applied, a scattering focal conic chiral nematic texture is observed, see Figure 4.

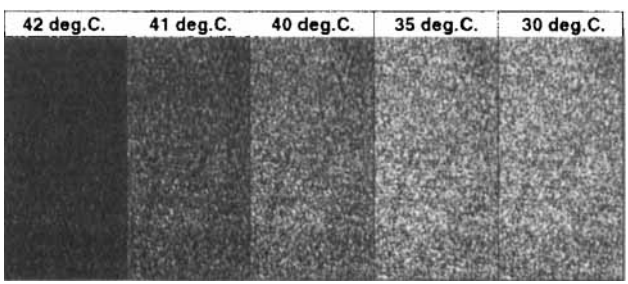

FIGURE 4 The scattering focal conic texture formed on cooling from the isotropic phase. No electric field is applied. See Color Plate XIII at the back of this issue.

However, on cooling from the isotropic phase with an AC electric field applied the materials form an aligned focal conic, or ULH, texture, see Figure 5.

As opposed to other flexoelectric systems, no external shearing forces are required to produce this ULH texture. Alignment is obtained by a combination of turbulent flow induced by the applied field and suitably treated surfaces.

Super-cooling is also observed in the thin optical cells we have studied, allowing room temperature flexoelectric switching to be observed.

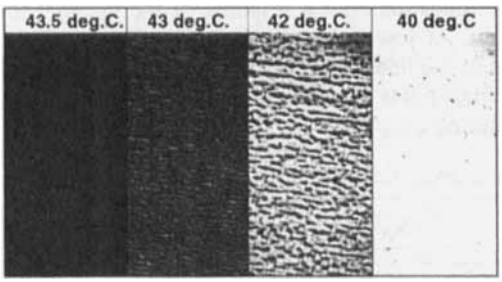

FIGURE 5 The alignment process - cool from isotropic phase whilst applying 9.5V/μm square wave at 80Hz. See Color Plate XIV at the back of this issue.

FLEXOELECTRIC SWITCHING PROPERTIES

Electro-optic Response

Unlike a conventional twisted nematic device there is no time delay between the field application (or polarity reversal) and the electro-

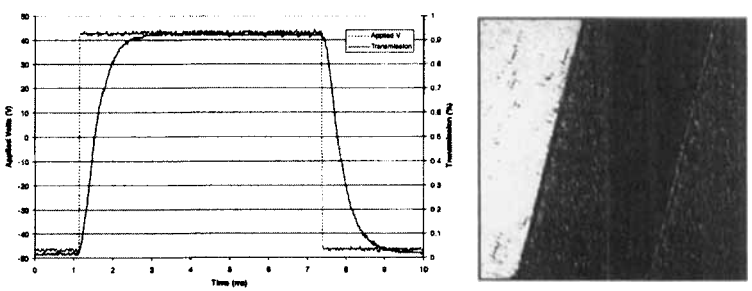

FIGURE 6 The optical response to a 9.5V/μm 80Hz applied field and the respective light and dark states. See Color Plate XV at the back of this issue.

optic response. The rise and fall times are also approximately equal since the applied field drives both directions. A contrast ratio greater than 90:1 is achieved, satisfying the requirement for application in display devices the scattering focal conic texture is clearly observable outside the electrode area.

Figure 7 illustrates the optical response of the material to an applied electric field. At low fields the electro-optic response is linear; a consequence of the linearity of the flexoelectric coupling. A nonlinear response at high fields is observed due to helix deformation that is a result of dielectric coupling.

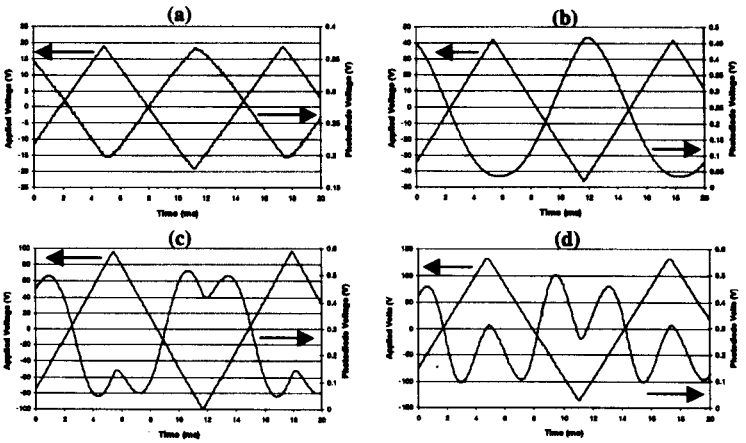

FIGURE 7 The flexoelectro-optic response of the material to a (a) 4V/μm, (b) 9V/μm, (c) 20V/μm and (d) 27V/μm 80Hz triangular applied field at 35°C.

Response Time

The optical response times were measured as the time taken for the transmitted light intensity to change from 0-90% of the peak to peak amplitude after field polarity reversal of an 80Hz square wave.

Response times of less than 1ms are readily achieved, see Figure 8. The magnitude decreases with increasing temperature as γ_1, the viscosity term in Eqn. (2), also varies with temp. The response times are also independent of the applied field [7] – the torque on the molecules is proportional to the magnitude of the applied field, hence the molecules rotate faster, but under higher fields the angle of rotation is greater, therefore there is effectively no change in the response time. Weak field dependence has been shown to be introduced by surface anchoring conditions [8].

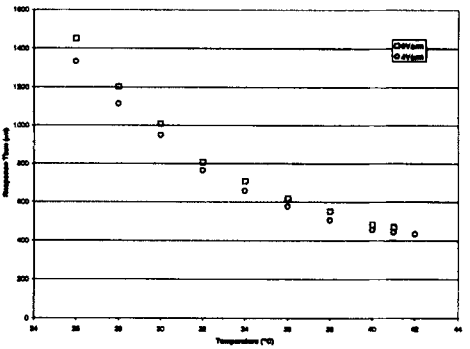

FIGURE 8 Optical response times as a function of temperature to an 80Hz square wave.

High tilt angles, of more than 22.5°, precluded sensible response time measurements being made from changes in light intensity, in the usual 0-90% manner, at higher fields.

Tilt Angle

The field induced optic axis tilt angle measurements in this paper were carried out using the rotating analyser technique. The experimental setup is the same as that previously used to characterise ferroelectric materials [9]. 10Hz square wave alternating voltages were applied to the sample, in the ULH texture, whilst the amplitude of the applied voltage and temperature were varied. The temperature could be lowered from just below T_c to below the crystallisation point due to supercooling. The material exhibited remarkably high tilt angles per unit field of ~2.4°/Vμm^{-1} in the linear regime before dielectric coupling effects manifest themselves in the form of helix unwinding at larger fields. The magnitude of the tilt angle is virtually independent of temperature, indicating that the pitch does not change significantly with temperature.

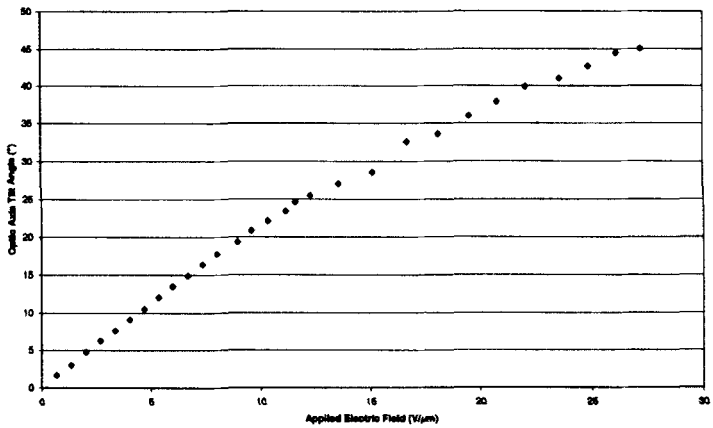

Figure 9 Optic axis tilt angle as a function of applied electric field, (10Hz square waveform, 40°C).

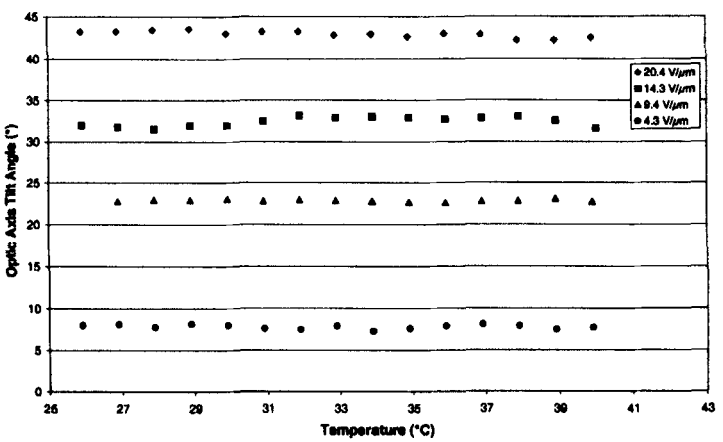

FIGURE 10 Optic axis tilt angle as a function of temperature, (10Hz square waveform).

CONCLUSION

The materials studied possess a room temperature nematic phase. Good alignment is possible by combining surface forces and applied AC fields whilst cooling through the isotropic – nematic transition. Switching times of the order of 500μs and contrast ratios of 90:1 are readily achieved. The tilt angles were found to be practically temperature independent and linear with the applied field. The constancy of the tilt angle is particularly useful for fixing the optical contrast as a function of temperature – the direction of the external polarisers can be optimised and fixed during device fabrication. The linear field dependence, lack of threshold field and bistability would also suggest that the material is particularly suited to grey scaling and optical modulation. Tilt angles of 22.5°, the optimum for birefringence displays, were obtained with moderate applied fields of 9.4V/μm. Fields of 26V/μm yielded tilt angles of 45°, providing optimal contrast ratios for DGH devices. We believe these are the highest tilt angles ever recorded for such fields.

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