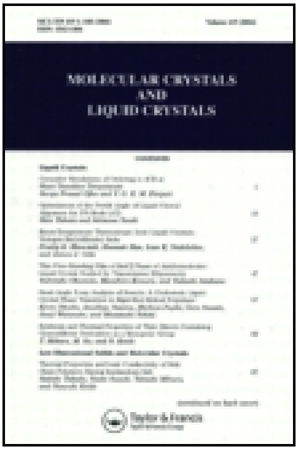

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C M Waters [a] , F C Saunders [b] [a] & M G Clark [b] [a]
[a] Department of Chemistry, The University, Huil, HU6 7RX, UK
[b] Royal Signals and Radar Establishment, Malvern, Worcestershire, WR14 3PS, UK

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STUDY OF CHOLESTERIC TEXTURES IN PHASE CHANGE DEVICES BY LASER LIGHT DIFFRACTION

C M WATERS*, F C SAUNDERS[+], and M G CLARK[+]
*Department of Chemistry, The University, Hull, HU6 7RX, UK
[+]Royal Signals and Radar Establishment, Malvern, Worcestershire, WR14 3PS, UK
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ABSTRACT

Photographic-recording and photomultiplier-recording laser light diffractometers have been constructed and used to study the cholesteric textures in phase change devices as a function of applied voltage and device parameters. The focal conic texture formed with increasing voltage gives diffraction peaks corresponding to 2π rotations of the director, whereas the texture formed by slow nucleation with decreasing voltage also gives "superlattice" lines corresponding to a 4π repeat, due to the different local structures of the textures combined possibly with tilting of the director. The repeat distances obtained by indexing the diffraction patterns agree well with microscopical and infra-red reflectance observations. Laser light diffraction appears to be a powerful technique for quantitative study of the non-uniform unwinding and re-forming of cholesteric twist in an electric field.

INTRODUCTION

It is well known that a twisted optical structure will give a Bragg-type reflection when the component of the photon wavevector parallel to the helical axis is correctly matched to the pitch. Following Durand[1], several authors[2,3] have studied the diffraction from thin films of cholesteric liquid crystal in which the helical axis lies approximately in the plane of the cell. These authors have apparently treated this diffraction as arising from a one-dimensional grating with a repeat distance along the helical axis corresponding to a rotation by π of the director. Our studies reported here indicate that for a range of cholesteric phase-change devices the observed diffraction and its variation with electric field applied across the film are significantly more complex and informative.

The theory of the cholesteric to nematic "phase change" transition induced by a sufficiently large electric or magnetic field has been treated by de Gennes[4] and Meyer[5], the latter author in particular emphasizing the extent to which the helical structure might become non-uniform as it is unwound by the field. Our comparisons of diffraction studies and optical microscopy indicate that the structures formed during unwinding and re-forming the twist are indeed non-uniform, supporting and extending previous reports[6,7].

EXPERIMENTAL

The devices studied were typically constructed from 3 mm thick ITO coated glass treated with either lecithin to induce homeotropic alignment of the liquid crystal director at the cell walls, or with obliquely evaporated silicon monoxide for homogeneous alignment, and spaced at 12 µm with Mylar. Light from a helium-neon laser was passed normally through the filled cell and the resulting diffraction studied as a function of the AC (typically 500 Hz - 1 kHz) voltage applied across the cell. The diffraction pattern was either cast onto a translucent screen and photographed by a camera mounted behind it on the axis of the laser beam (Figure 1), or recorded by a photomultiplier mounted on a travelling platform which traversed horizontally across the diameter of the pattern. The motion of the photomultiplier was linked to a rheostat in such a way that a voltage proportional to the distance across the pattern was applied to the x amplifier of an xy plotter and the output from the photomultiplier applied to the y amplifier to yield diffractograms as shown in Figure 2.

Observations were also made by standard microscopical techniques, and measurements of the zero-field pitch from the selective reflection in the infra-red.

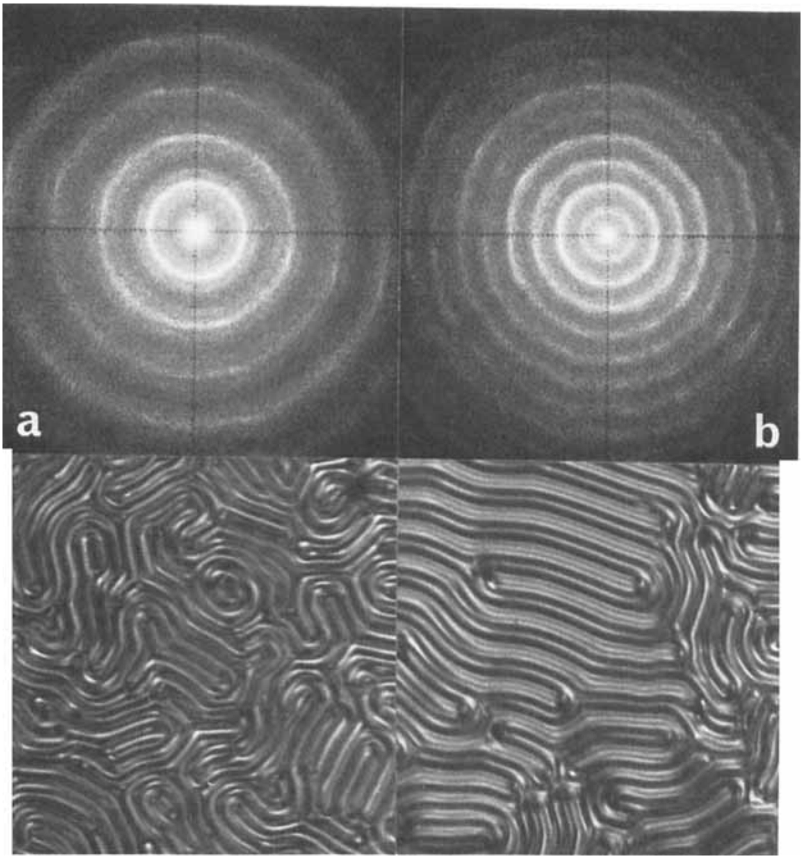

FIGURE 1 Upper panels show photographs of the HeNe laser light diffraction patterns of a mixture of biphenyl materials ($C_nH_{2n+1}\cdot C_6H_4\cdot C_6H_4\cdot CN$, n = 3, 5, and 7) with 4.0% CB15 ($CH_3CH_2CH(CH_3)CH_2\cdot C_6H_4\cdot C_6H_4\cdot CN$) cholesteric dopant in a homeotropically aligned cell for (a) increasing voltage and (b) the slowly nucleated texture obtained on decreasing the voltage from above threshold. The lower panels show the corresponding textures seen between crossed polars. The zero-field pitch of this material is 3.6 μm.

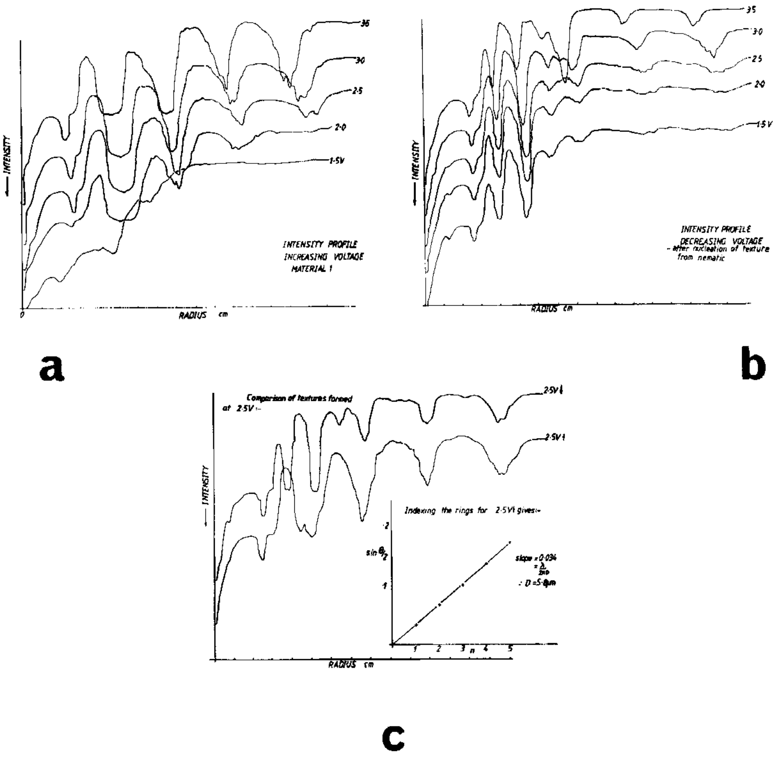

FIGURE 2 Diffractograms of a mixture of PCH materials ($C_nH_{2n+1}\cdot C_6H_{10}\cdot C_6H_4\cdot CN$, n = 3, 5, and 7) with 2.8% CE1 ($CH_3CH_2CH(CH_3)CH_2\cdot C_6H_4\cdot C_6H_4\cdot COO\cdot C_6H_4\cdot CN$) cholesteric dopant in a homeotropically aligned cell (a) for increasing voltage, (b) for decreasing voltage, and (c) showing comparison of diffractograms for increasing and decreasing voltages at 2.5 V and (inset) indexing to eqn (1) of the text to yield a value for the basic repeat distance at 2.5 V of 5.8 μm. The corresponding value obtained from microscopical observations is 5.7 μm, and the zero-field pitch measured by IR reflection is 5.3 μm.

RESULTS AND INTERPRETATION

The diffraction patterns reported here are those obtained when the cholesteric is in a focal conic texture. In both diffractometers the beam diameter was sufficiently large that the pattern obtained is averaged over a large number of orientations of the helical axis, giving a series of diffraction rings analogous to an X-ray powder pattern. Some polarization effect was observed, but has not been studied in detail.

As the applied electric field is raised from zero, the planar texture is converted to focal conic fingerprint texture, when, as seen in both Figs 1a and 2a, a series of over 5 orders of diffraction are seen quite strongly. The spacing of these orders changes only slightly until close to the critical field for the transition to the field-induced nematic. When the focal conic is allowed to nucleate from the field-induced nematic by lowering the applied field to below threshold, the diffraction peaks re-appear together with intermediate "superlattice" lines corresponding to twice the basic repeat distance (Figs 1b and 2b). Diffractograms for both increasing and decreasing voltage also show other reproducible fine structure. Qualitatively similar results were obtained for a variety of materials with zero-field pitches in the range 1.5 to 10 μm (pitch:thickness ratio 0.1 - 1) with both homogeneous and homeotropic surface alignment.

As seen from Figure 2c, the basic diffraction lines which appear for both increasing and decreasing voltage index well to the Bragg law

$$2d \sin(\theta/2) = n\lambda \qquad n = 1, 2, 3, \ldots \qquad (1)$$

where d is the basic repeat distance, and θ and λ are the angle of diffraction and wavelength of the light inside the liquid crystal, both calculated from the values actually measured in air using the average refractive index. In all our experiments the value obtained for d corresponds to a full pitch (2π rotation of the director). This has been confirmed experimentally by measurements of infra-red reflection and by calibrated measurements in the polarizing microscope of the distance between sharp dark lines in the texture (A - A' in Figure 3).

This interpretation of the texture is in agreement with Kawachi et al[8]. Cladis and Kléman[9] interpreted successive sharp lines of the cholesteric domain texture obtained by

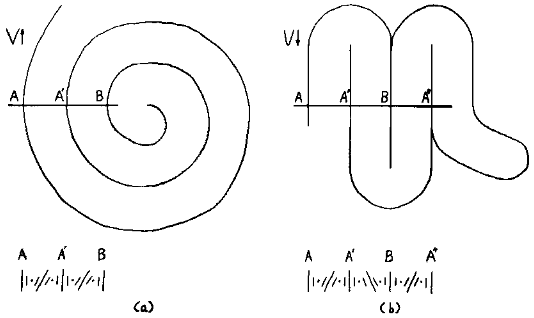

FIGURE 3 Sketches of idealized local structure of textures for (a) increasing voltage and (b) decreasing voltage. Possible tilt profiles across the sections A - A' - B are also shown.

evaporation of an isotropic solvent just below the clearing point as corresponding to π rotation of the director, suggesting that this texture is different. Certainly the "threads" are packed differently.

The additional lines obtained when the voltage is lowered from above threshold correspond to twice the basic repeat distance, ie A - B in Figure 3. Evidently, the folding of the threads is such as to make adjacent threads inequivalent, and we hypothesize that the mechanism for this inequivalence is director tilt. Figure 3 shows how the different packing of threads in the increasing voltage and decreasing voltage textures would cause tilt to generate inequivalence in the latter, but not in the former, case. Consistently with this interpretation, the centre of each thread, which corresponds to π rotation of the director from a sharp line, is marked by a diffuse line which is normally coloured and sometimes displaced. The splitting of diffraction peaks noticeable for both increasing and decreasing voltage may be related to the long range ordered packing of the threads generating additional much longer repeat distances.

Qualitatively the same results are obtained with both homeotropic and homogeneous boundary conditions, although the former give slightly larger values of pitch, indicating that dilation of the cholesteric twist by the homeotropic boundaries may be a factor in the slightly lower threshold voltages observed with these conditions.

From our observations the field-induced cholesteric to nematic transition appears to occur by formation of increasing nematic domains separating virtually unperturbed slabs of cholesteric one full pitch thick. Essentially the same conclusions have been drawn from microscopical observations on similar phase change devices by B Needham (personal communication), and for cells with large pitch: thickness ratios by Yu and Labes[6].

Since the positions, widths, intensities, and fine-structures of the diffractograms such as Figure 2 are very reproducible experimentally, we believe that this technique can be used to obtain detailed quantitative information on the packing of the helix in cholesteric structures by comparing the observed diffraction pattern with one calculated for the hypothesized structure. We have obtained encouraging preliminary results for such calculations.

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