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

Director configuration of a ferroelectric liquid crystal in a cell with antiparallel surface tilt

L. Z. Ruan[a]; J. R. Sambles[a]; J. Seaver[b]
[a] Thin Film Photonics Group, Department of Physics, University of Exeter, Exeter, England [b] Central Research Laboratories Ltd, Middlesex, England

To cite this Article Ruan, L. Z. , Sambles, J. R. and Seaver, J.(1996) 'Director configuration of a ferroelectric liquid crystal in a cell with antiparallel surface tilt', Liquid Crystals, 21: 6, 909 — 914
To link to this Article: DOI: 10.1080/02678299608032909
URL: http://dx.doi.org/10.1080/02678299608032909

LIQUID CRYSTALS, 1996, VOL. 21, NO. 6, 909–914

Director configuration of a ferroelectric liquid crystal in a cell with antiparallel surface tilt

by L. Z. RUAN, J. R. SAMBLES* and J. SEAVER†
Thin Film Photonics Group, Department of Physics, University of Exeter,
Exeter EX4 4QL, England
†Central Research Laboratories Ltd, Dawley Road, Hayes, Middlesex UB3 1HH,
England

(*Received 30 May 1996; accepted 5 August 1996*)

Using the half-leaky guided wave technique we have characterized the optical director profile of a ferroelectric liquid crystal in a homogeneously aligned cell with rubbed nylon surfaces. At high temperatures the N* phase is in the expected splayed state, with opposite surface tilts of the order 3°. On cooling into the S_A phase, the director corresponds to that of an almost uniform slab with a tilt of 5°. Further cooling into the S_C^* phase does not produce the expected chevron structure; rather a tilted-bookshelf structure is recorded with an initially, at high temperatures, increased tilt of 8°. As the sample is further cooled, this tilt diminishes and eventually at room temperature changes sign to $-2°$. In addition, the room temperature S_C^* phase has a uniform twist of about 1·4° away from the initial alignment direction. This accords well with the polarization microscopy measurement of an extinction angle of about 1·5° for this cell.

1. Introduction

The director profile in ferroelectric liquid crystal cells with different surface treatments is important for a range of device applications. If we are to be able to model predictively device performance, then detailed knowledge of the static director configuration is essential. For device-type structures, it is the homogeneous alignment which is most important and much work has been undertaken in characterizing homogeneously aligned S_C^* cells with different surface treatments. This includes studies of both the smectic layer structure and the optical director profile [1–5]. Such studies have established the presence of the chevron layer structure [1,2] in homogeneous cells. They have also established various types of structure depending on the relationship between layer and surface tilt [4,5], leading to the general classification of C1 and C2 states.

Conventional methods for investigating the cell structure are polarization microscopy and X-ray diffraction. The latter is specifically useful in giving details of layer structure, but tells us little as regards the director twist and tilt. On the other hand polarization microscopy gives information about the optical tensor properties, yielding no direct information as regards the layers. This technique is however limited in that it gives an integrated optical response through the cell and gives little information on specific details of the director twist and tilt profiles.

In this study we apply the half-leaky guided mode (HLGM) technique [6,7], which allows evaluation of the spatial distribution of the director profile through the cell, to investigate the profile of a homogeneously aligned ferroelectric liquid crystal, material 744, in a cell with rubbed nylon alignment.

In the HLGM geometry, the liquid crystal film under study is sandwiched between a low index glass plate (with an index ideally lower than the lowest index of the liquid crystal) and a high index glass prism (with an index ideally higher than the highest index of the liquid crystal). This difference in indices gives a special range of incidence angle between the true critical angle of the high index prism and the low index plate and the pseudo-critical angle between the high index prism and the liquid crystal. In this angle range, half-leaky guided modes may propagate in the liquid crystal layer, the optical field being fully internally reflected at the interface of the low index plate and the liquid crystal. Over this angle range, sharp reflectivity features are recorded which are sensitive to details of the director profile in the cell. By further exploring the p to s conversion reflectivity, high sensitivity to the director tilt/twist profile is obtained.

2. Experimental

An approximately 2 μm thick layer of chiral liquid crystal 744 is sandwiched between a high index glass

---

*Author for correspondence.

plate ($n_1 = 1{\cdot}733$ at 632·8 nm) and a low index glass substrate ($n_2 = 1{\cdot}459$ at 632·8 nm). These two different index plates are coated with a thin (~ 50 nm) layer of transparent conductor (indium tin oxide, ITO). On top of these electrodes are deposited layers of polyimide and nylon for the high index plate and just nylon for the low index substrate. The polyimide is there as an electrical buffer, and the two nylon layers are rubbed to provide low tilt homogeneous alignment of the liquid crystal. The complete cell is placed into intimate optical contact with a high index prism using matching fluid. Thus the high index plate, prism and matching fluid become effectively one optical element. The sample construction is illustrated in Figure 1.

This complete assembly is placed into a temperature controlled environment on a computer controlled rotating table and then heated into the isotropic phase (about 124°C). Then, following the procedure described in detail by Yang and Sambles [6], angle dependent reflectivities R_{ss}, R_{pp} are recorded at a wavelength of 632·8 nm. These were compared with modelling theory to characterize the ITO, nylon and polyimide, as well as the isotropic phase of the liquid crystal.

Cooling slowly ($\sim 1{\cdot}0°\mathrm{C\,h^{-1}}$) into the N* phase (about 103·7°C) gives a well-aligned monodomain. Then, with the rubbing direction of the cell aligned at $\sim 45°$ to the plane of incidence, both R_{ss} (TE in to TE out) and the polarization conversion signal R_{sp} (TE in to TM out) were recorded. This latter signal is very sensitive to details of the director tilt/twist profile.

Further slow cooling takes the cell down into the S_A phase and finally into the S_C^* phase. In the S_A phase data were taken at 75·0°C and in the S_C^* phase data were recorded at 59·1, 37·7 and 25·0°C.

On examining the cell at room temperature using polarization microscopy, it was found that this slowly cooled cell was a monodomain having an extinction angle about 1·5° away from the rubbing direction of the cell.

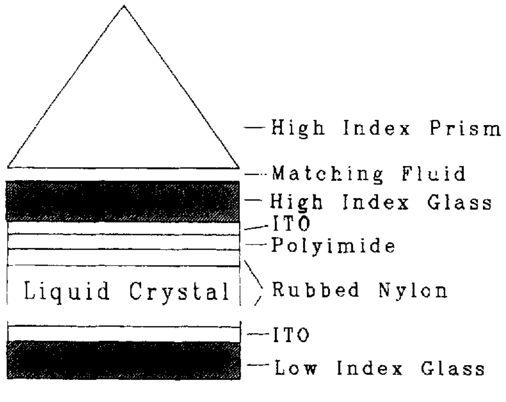

Figure 1. Schematic of the half-leaky guided cell.

3. Results and discussion

By fitting the angle dependent HLGM reflectivity data using multilayer optics theory, we are able to characterize the cell in detail. First we need to characterize the boundary layers and this is done by fitting data for the isotropic phase. The slightly absorbing ITO layers each have a thickness of 49 nm with an optical permittivity of $\varepsilon_{\mathrm{ITO}} = 3{\cdot}235 + i0{\cdot}015$. In fitting the polyimide film, there is a degeneracy between the thickness and the permittivity. For a thickness of 20 nm it requires $\varepsilon_{\mathrm{poly}} = 2{\cdot}528 + i0{\cdot}001$. The rubbed nylon films each have a thickness of 26 nm with anisotropic permittivities of $\varepsilon_{\parallel} = 3{\cdot}000 + i0{\cdot}001$ and $\varepsilon_{\perp} = 2{\cdot}300 + i0{\cdot}001$. These two films are uniaxial with the uniaxial axis along the rubbing direction. It should be stressed that there is some uncertainty in all these fitting parameters, particularly for the weakly absorbing layers, due to the optical thickness being the dominating factor.

Hence we could fit the data with a range of polyimide thicknesses provided we adjust $\varepsilon_{\mathrm{poly}}$ accordingly. We choose the above set because all the parameters are sensibly within their expected range. Using these boundary parameters we can now proceed to a detailed analysis of the data taken in the N*, S_A and S_C^* phases.

From the rubbed nylon surface preparation, it is anticipated that the nemetic director will be aligned homogeneously in the rubbing direction with a small surface pretilt. Fitting the reflectivity data in the N* phase at 103·7°C (figure 2), we find that the stable configuration is a horizontal state having a top (high index plate) surface tilt of $+2{\cdot}5°$ and a lower (low index

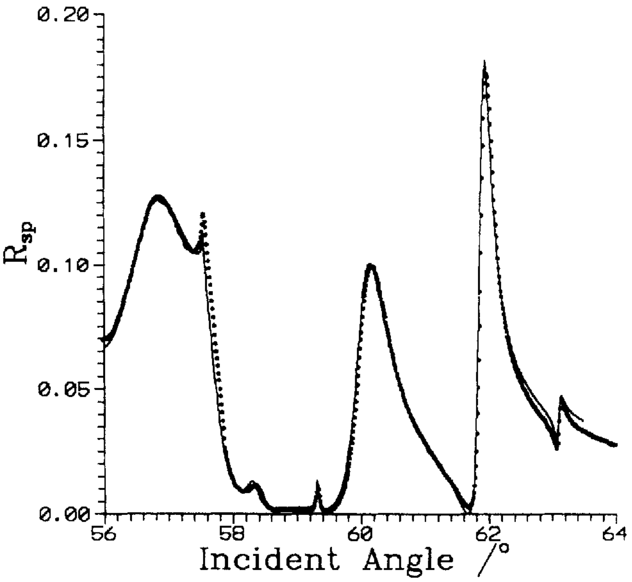

Figure 2. Polarization conversion reflectivity data (crosses) in the N* phase at 103·7°C fitted with a multilayer optics model (continuous line) of the liquid crystal cell.

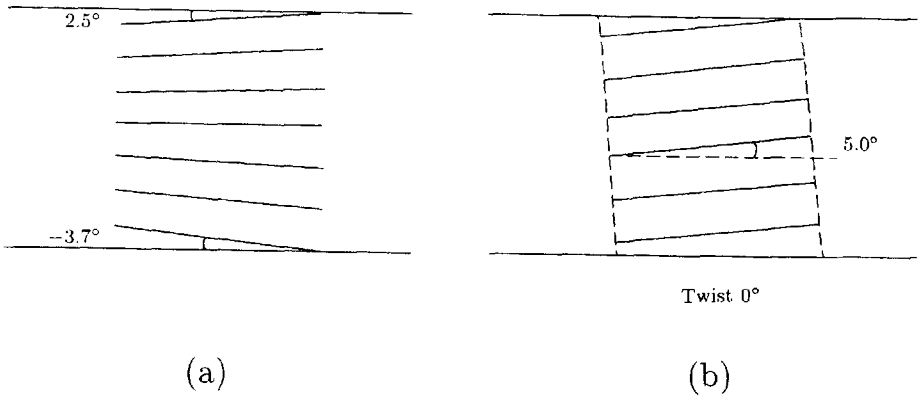

Figure 3. The director tilt profile in the cell; (*a*) in the N* phase, (*b*) in the S_A phase.

plate) surface tilt of −3·7°, measured from parallel to the surfaces. This is shown in figure 3 (*a*).

The state is thus a splayed state with a total splay of 6·2° as expected for parallel rubbed surfaces. In addition there are surface twist angles of +3·4° (top) and −1·7° (bottom) measured from the rubbing direction. This may be due to plate/rubbing misalignment, or it may be also the natural chirality of the material causing an overall twist of some 5·1° in the cell. The full modelling treats the twist and tilt as varying linearly throughout the liquid crystal layer. These detailed profiles give high quality fits to the data, with $\varepsilon_{\parallel}=2{\cdot}5384+i0{\cdot}0005$ and $\varepsilon_{\perp}=2{\cdot}2060+i0{\cdot}0002$ and a cell thickness of 1·985 μm.

On cooling into the S_A phase, because of the strong density wave or layer constraints, the director twist is expected to be removed. Comparing our data taken in the S_A phase at 75·0°C (figure 4) with optical multilayer modelling theory we find a uniform director alignment apart from very thin surface regions (⩽50 nm). Fitting the data with a uniform slab model (figure 3 (*b*)) we find a director tilt of +5·0° throughout the cell, with the director now aligned along the rubbing direction. The cell now has a thickness of 1·980 μm with $\varepsilon_{\parallel}=2{\cdot}6440+i0{\cdot}0008$ and $\varepsilon_{\perp}=2{\cdot}2000+i0{\cdot}0001$. Thus we see the S_A phase structure is primarily a tilted bookshelf (there is no chevron) with thin surface regions where presumably the director attempts to take up the aligning surface tilt.

The interesting observation is that the overall director tilt is now more than that of either surface in the nematic phase. Density wave layer shrinkage is probably the cause of this tilt. This increase of surface tilt is in agreement with previous work [8] in which it was recorded that the pretilt angle in the bookshelf S_A phase was higher than that found in either the nematic phase or in the chevroned S_A phase. Not too surprisingly, this supports the idea that it is not just the surface preparation which dictates director structure in a cell, but also the thermodynamic properties of the material and the thermal history of the cell. In addition there is some small asymmetry between the two surface aligning layers which may influence the structure.

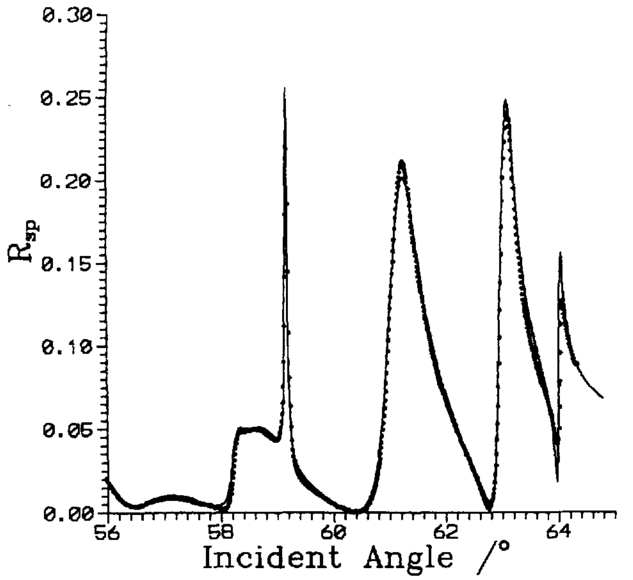

Figure 4. Polarization conversion reflectivity data (crosses) in the S_A phase at 75·0°C fitted with a multilayer optics model (continuous line).

We now explore the director profile in the S_C^* phase, with data recorded at 59·1, 37·7 and 26·0°C. At 59·1°C the cell now has a uniform region of thickness of only 1·62 μm with the S_C^* director having primarily a very simple, and surprising, slab structure with a tilt of 8·0° and a twist of 2·8°. In addition there are two boundary layers. At the top, high index plate, there is a region of liquid crystal of thickness 44·0 nm over which the director is modelled as twisting uniformly from 0·5° to 2·8°, while tilting uniformly from 5·0° at the surface to 8·0° in the bulk. At the low index plate interface, there is a thicker region of 300 nm thickness in which the director is twisted uniformly from −0·2° to 2·8° and in which the director is tilted uniformly from 6·3° at the surface to 8·0° in the bulk. The fitted data are shown in figure 5. Note that the overall cell thickness is now 1·96 µm, which is little changed from the S_A phase, while $\varepsilon_{\parallel}=2{\cdot}7030+\mathrm{i}0{\cdot}0008$ and $\varepsilon_{\perp}=2{\cdot}2134+\mathrm{i}0{\cdot}0003$ at this temperature of 59·1°C.

Further reduction in temperature to 37·7°C still leaves quite a simple structure, the fit for the data being shown in figure 6. Once again the majority of the cell (about 1·42 µm) is a uniform slab, now tilted by 6·6° with a twist of 3·0°. The two surface regions are somewhat different from those before. Now both have thicknesses of 0·25 µm, with the director at both surfaces tilting uniformly from 5·0° to 6·6°, and the twist grading uniformly from 0° to 3·0°. The overall cell thickness is reduced slightly to 1·92 µm, with $\varepsilon_{\parallel}=2{\cdot}7510+\mathrm{i}0{\cdot}0001$ and $\varepsilon_{\perp}=2{\cdot}2320+\mathrm{i}0{\cdot}0001$.

The final data taken at 26·0°C (figure 7) give once again a largely uniform slab director profile in the cell except for two thin boundary regions. Now a tilt of −2·0° and a twist of 1·4° over a thickness of 1·80 µm characterizes the bulk of the director profile. At the upper, high index plate surface, there is a layer of thickness 40 nm in which the director tilts uniformly from 5·0° (at the surface) to −2·0° (in the bulk), while it twists uniformly from 0° (at the surface) to 1·4° (in the bulk). On the bottom surface, low index plate, there is a region of thickness only 20 nm in which the director tilts uniformly from −4·0° (at the surface) to −2·0° (in the bulk), while it twists uniformly from 2·0° (at the surface) to 1·4° (in the bulk). The director profiles at these three temperatures are shown in figure 8.

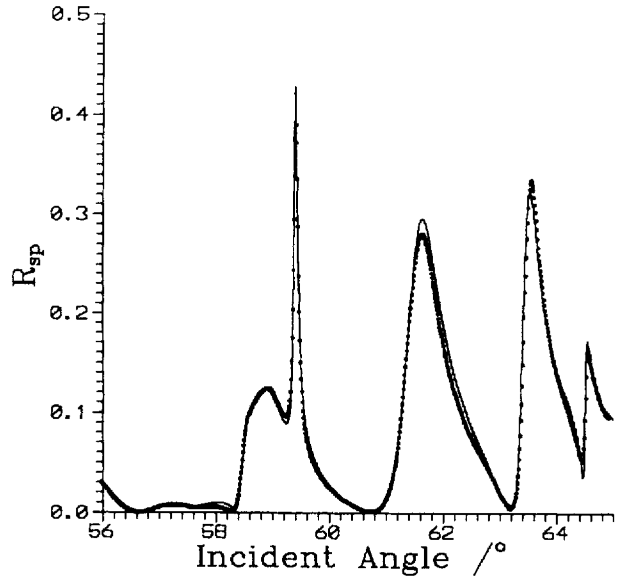

Figure 5. Polarization conversion reflectivity data (crosses) in the S_C^* phase at 59·1°C fitted with a multilayer optics model (continuous line).

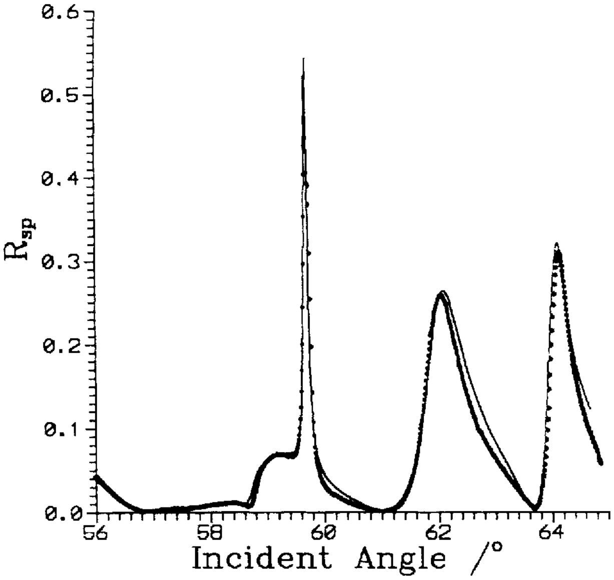

Figure 6. Polarization conversion reflectivity data (crosses) in the S_C^* phase at 37·7°C fitted with a multilayer optics model (continuous line).

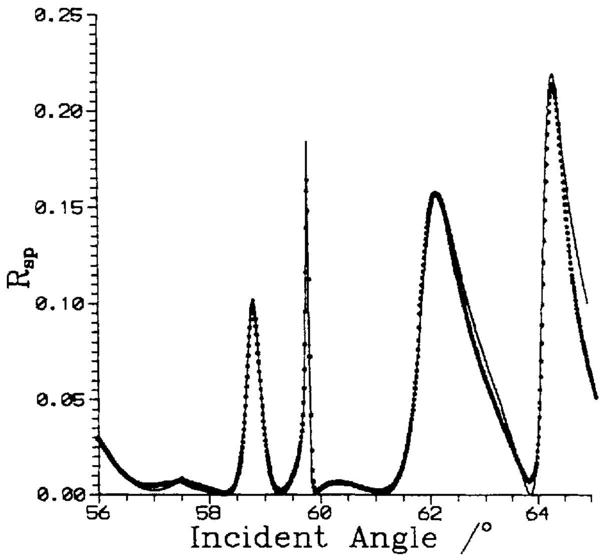

Figure 7. Polarization conversion reflectivity data (crosses) in the S_C^* phase at 26°C fitted with a multilayer optics model (continuous line).

These results are rather unusual. Of course the splayed and slightly twisted state in the nematic phase is expected, while the S_A phase may be anticipated to form a tilted bookshelf. However the absence of a chevron in the S_C^* phase, particularly in view of the parallel rubbing is surprising. Any attempt at fitting the data with typical

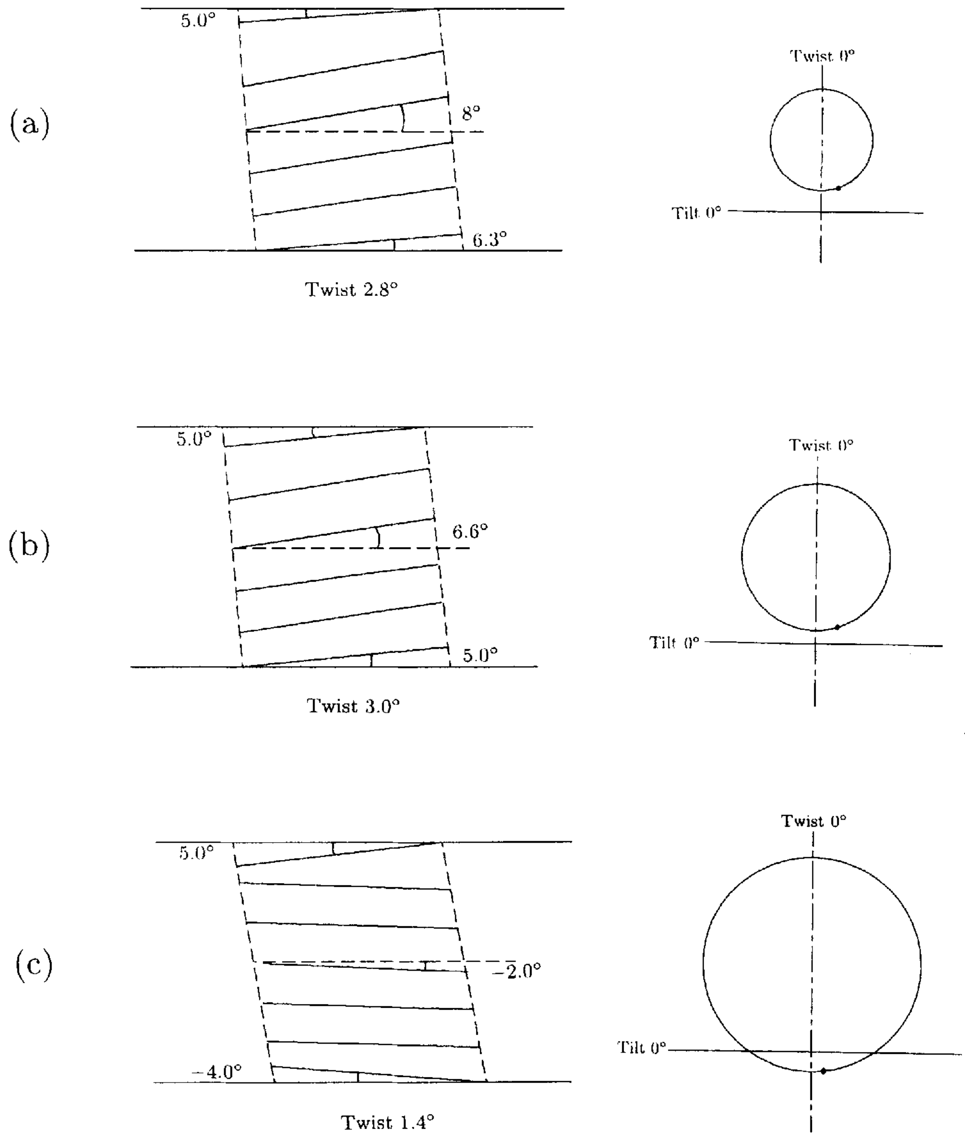

Figure 8. Sketch of director structure found in the cell at (*a*) 59·1, (*b*) 37·7 and (*c*) 26°C, respectively.

director profiles associated with the chevron state failed. Our data are consistently fitted in the S_C^* phase with most of the cell director being everywhere parallel. Of course this gives no direct information as regards the layer structure. Nevertheless, it is extremely difficult to conceive of any chevron structure, particularly one in which the director of the chevron interface has the same tilt as the remainder of the cell, which is not full of defects, the chevron interface running across the cell and intersecting with the cell walls. In addition, observations using optical microscopy show no ‘mountain defects’ which would generally be present for chevron structures.

We also note that on cooling from 59·1 through 37·7 to 26·0°C the majority of the director in the cell changes from a tilt of 8°, first to 6·6° and finally to −2·0°, with small changes in twist. The most likely explanation for the observed behaviour is that, on cooling, as the cone angle increases so the director in the bulk of the cell moves from initially having an up tilt to finally, at low temperatures, a down tilt of −2°. This is illustrated in figure 8. The layers may have to tilt further or shear off to accommodate this, the amount depending on the increase in cone angle as the temperature is reduced. However the change in optical cone angle from 59·1 to 26·0°C is about 5°, while from 37·7 to 26°C it is under 1°. These changes are clearly insufficient to account for the changes observed in this study. It should of course be appreciated that the optical data only yield information on the director profile and not the layer structure. The primary point is that with the rubbed nylon surfaces, the director direction is largely constrained throughout the cell to lie nearly parallel to the original alignment, the layers accommodating this without recourse to the formation of a chevron. It is interesting to note that for a 90° twisted cell, Lavers *et al.* [9] observed in-plane director alignment for the S_C^* phase, the surface forces dominating the smectic layering. In our case the layering is retained, the relative twist of the two surfaces being only 5·1°.

It is apparent from these results that further exploration of the alignment of the S_C^* phase in cells with different surface treatments is needed in order to explore the effects of chevron formation and layer shear (density wave twist).

4. Conclusions

Using the half-leaky guided mode technique we have characterized the optic director profile in a homogeneously aligned ferroelectric liquid crystal cell with parallel rubbed nylon surfaces. In the N* phase, the expected splayed and slightly twisted state is recorded with surface tilts of the order of a few degrees. On cooling into the S_A phase, an almost uniform slab having 5·0° tilt is found. Further cooling into the S_C^* phase does not produce the expected chevron; instead the director remains largely aligned in the original rubbing direction with, at higher temperatures close to the S_A phase, an increased tilt of 8·0°, this reducing and finally reversing to $-2{\cdot}0°$ at room temperature. Also at room temperature (26·0°C), the director is found to be twisted out by only 1·4°, which accords well with the observation of an extinction angle of 1·5° recorded by polarizing microscopy. These results indicate that strong azimuthal anchoring is dominating the alignment, the smectic layers accommodating the changes with temperature of cone angle and layer spacing. They also imply, since there is no chevron, that the defective boundary at one surface allows relatively free motion of the molecules along the alignment direction.

The authors thank the EPSRC and CRL for their support. Dr Emma Wood's help is also gratefully acknowledged. This work originated as part of an EPSRC/DTI LINK programme.

References

[1] Reiker, T. P., Clark, N. A., Smith, G. S., Parmar, D. S., Sirota, E. B., and Safinya, C. R., *Phys. Rev. Lett.*, 1987, **59**, 2658.
[2] Clark, N. A., and Reiker, T. P., *Phys. Rev. A*, 1988, **37**, 1053.
[3] Oh-e, M., Isogai, M., and Kitamura, T., *Liq. Cryst.*, 1992, **11**, 101.
[4] Itoh, N., Koden, M., Miyoshi, S., and Wada, T., *Jpn. J. appl. Phys.*, 1992, **31**, 852.
[5] Itoh, N., Koden, M., Miyoshi, S., and Wada, T., *Liq. Cryst.*, 1993, **15**, 669.
[6] Yang, F., and Sambles, J. R., *Opt. Soc. Am. B*, 1993, **10**, 858.
[7] Yang, F., and Sambles, J. R., *Liq. Cryst.*, 1993, **13**, 1.
[8] Bonvent, J. J., van Haaren, J. A. M. M., Gnossen, G., Verhulst, A. G. H., and van der Sluis, P., *Liq. Cryst.*, 1994, **18**, 723.
[9] Lavers, C. R., Sambles, J. R., Raynes, E. P., and Cann, P. S., *Liq. Cryst.*, 1993, **15**, 749.