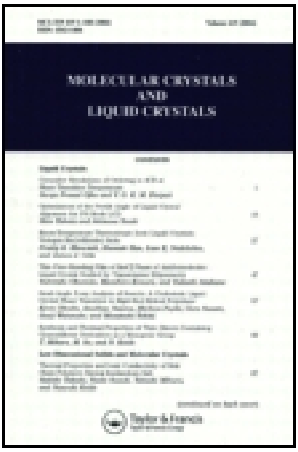

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Electrohydrodynamic Origin of Striped Texture in Ferroelectric Liquid Crystal Cells

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ELECTROHYDRODYNAMIC ORIGIN OF STRIPED TEXTURE IN FERROELECTRIC LIQUID CRYSTAL CELLS

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Abstract Evidence is presented that the striped texture associated with quasi-bookshelf structure formation is electrohydrodynamic in origin.
Results are presented and a model proposed in which this particular striped texture is formed as a result of electrohydrodynamic instabilities similar to Williams domains.

INTRODUCTION

The striped texture formed when a low frequency (<1kHz) AC voltage of about 20-30V RMS is applied to a planar aligned ferroelectric liquid crystal with a Ps greater than $10nC.cm^{-2}$ has been described as being formed from parallel zig-zag walls[1] (Fig. 1).

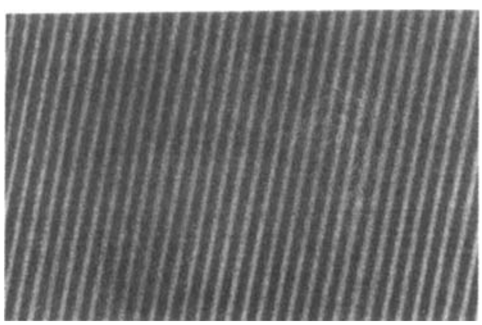

FIGURE 1 Striped texture for a 2μm cell of SCE13

The formation of the striped texture is associated with that of the so-called quasi-bookshelf structure[2], which shows as an increase in the apparent bistable tilt angle.

A model of the observed texture was presented by Lejcek and Pirkl[3] based on a description of the striped texture in the SmA phase by Pavel and Glogorova[4].

Here we offer an alternative account based on the assumption that an electrohydrodynamic effect is involved. The explanation given here is not applicable to the SmA example which we agree is probably an electroclinic phenomenon[4].

EXPERIMENTAL

Most work discussed in this paper was carried out on Merck materials SCE13, ZLI-3654 and ZLI-4655-100. These have the phase sequences:

SCE13:	SmC* 61 SmA 86 N* 101 I	(°C)
ZLI-3654	SmC* 62 SmA 76 N* 86 I	(°C)
ZLI-4655-100	SmC* 61 SmA 72 N* 76 I	(°C)

with Ps values of +27.8, -29.0 and +22.6 $nCcm^{-2}$ respectively at 20°C.

The alignment material used was MgF_2 evaporated at 60° from normal incidence to a thickness of about 10-20nm. It was chosen because it is stable, relatively easy to evaporate, and requires no rubbing thus avoiding associated contamination and control problems. Also the thin, porous nature of these films means that they do not accumulate charge very readily. This is important to avoid inhibition of electrohydrodynamic effects. The liquid crystal optic axis in the N* and SmA phases aligns perpendicular to the evaporation direction. No clear distinction could be discerned in subsequent cell operation when top and bottom electrodes were evaporated from the same or opposite sides and they were usually evaporated from the same side.

The spacers used were epostar plastic spheres. Cell thickness was estimated from interference colours. In many cases thickness could be verified by measuring the periodicity of the stripes since this has been shown to be similar to the cell thickness[1].

EVIDENCE FOR ELECTROHYDRODYNAMIC EFFECT

The following is a list of observations which, we believe, point to an electrohydrodynamic process:

(a) The threshold voltage for stripe formation (here defined as the lowest voltage for which the whole pixel is covered in stripes) is independent of thickness for cells ≥ 2μm thick. For thinner cells the threshold appears to be lower, probably due to surface effects. (Figure 2).

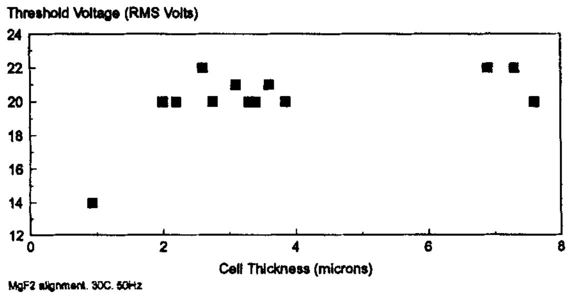

FIGURE 2 Threshold voltage v Cell Thickness for some SCE13 cells.

b) Slightly above threshold small particles (e.g. small spacers) in the liquid crystal move suggesting material flow. The motion is perpendicular to the stripes (along the layers) (Figure 3).

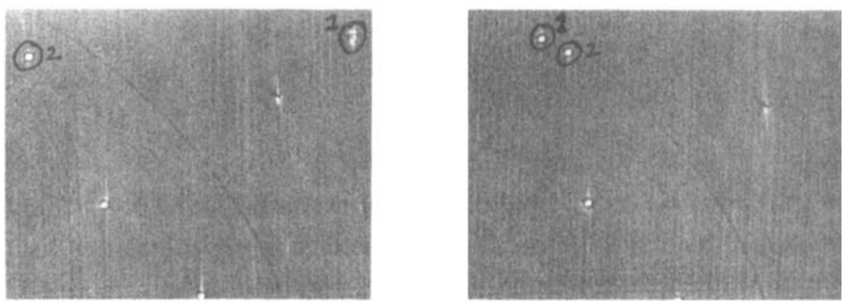

FIGURE 3 Particle motion

(c) During stripe formation, with suitable liquid crystals, the quasi-bookshelf geometry results. In figure 4 it can be seen that the number of layers must change in going from the chevron to bookshelf geometry to maintain a constant volume, how this can be achieved by a purely field effect is not clear. However such a rearrangement of the layers under the large shearing forces associated with flow conditions seems more feasible.

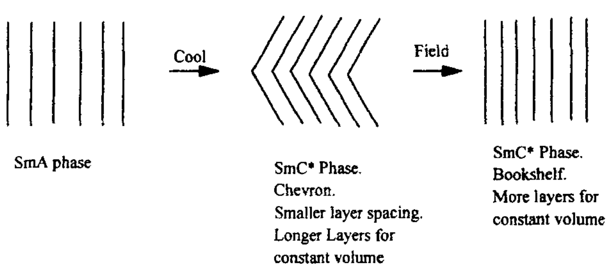

FIGURE 4 Layer structures after treatment.

(d) Self-recovery from alignment defects can be induced by applying the low frequency AC voltages for some time to both ferroelectric and antiferroelectric cells[5]. The authors of ref. 5 attributed the recovery to an internal shear in the sample due to layer switching between bookshelf and quasi-bookshelf geometries. An alternative, and perhaps more likely, account of this is that it is due to a gradual realignment due to flow.

POSSIBLE MECHANISMS

Figure 5 shows stripes in a 5μm cell in the process of propagation.

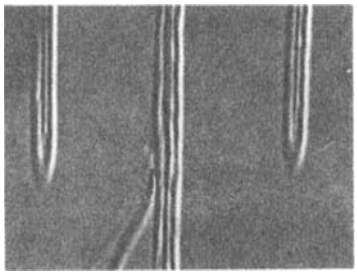

FIGURE 5 Stripe Propagation in a 5μm cell of SCE13.

Labroo et al[6] proposed an electrohydrodynamical mechanism for the propagation of stripes in the SmC* phase of DOBAMBC. They noticed the ellipsoidal shape of the propagating tip and described it as DC plug flow arising from space charges associated with conductivity anisotropy. An electric pressure was claimed to form at the focus of the ellipse which, above a field threshold, results in a pumping action driving the stripe on.

The threshold voltages were low (about 7V at 10 μm thickness). Also a field dependence was noted. Clearly a different mechanism should be sought here as our observations suggest their phenomenon is qualitatively different.

Electrohydrodynamic Instability.

One possible mechanism is to consider the process as an electrohydrodynamic instability similar to those leading to Williams domains. For nematics these show voltage thresholds independent of cell thickness as is the case here. Such instabilities have been reported and described in SmC by a number of workers and indeed a voltage threshold has been observed [7-9]. However there does not appear to be any reference to such instabilities in SmC* with high Ps. The Carr-Helfrich requirements for an instability namely that the dielectric anisotropy ($\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp}$) and the the conductivity anisotropy ($\Delta\sigma = \sigma_{\parallel} - \sigma_{\perp}$) should have opposite sign[10] may be applied within the smectic layers for a planar aligned sample. In the case of high Ps SmC* the interaction of the (off axis) polarisation with the field will effectively enhance the effect of negative dielectric anisotropy. Figure 6 shows

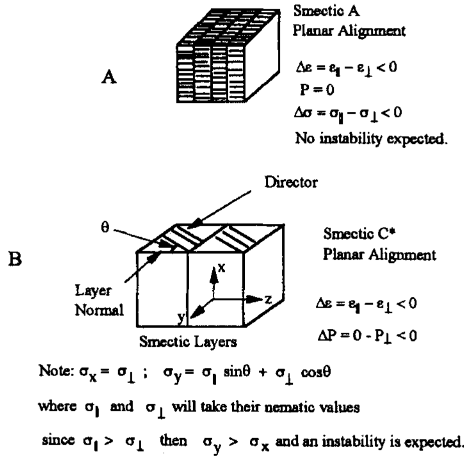

FIGURE 6 SmA compared with SmC*

schematically slabs of SmA (A) and SmC* (B) layers. In the SmA case for a material with $\Delta\varepsilon<0$, $P=0$ and since $\Delta\sigma<0$ there should be no instability. In the case of SmC*, however, the tilted layers mean that the conductivity in the y direction as indicated in Figure 6B has a contribution from the larger conductivity parallel to the molecular axis thus the torques arising from field interaction with $\Delta\varepsilon$ (+ Ps) and $\sigma_y - \sigma_x$ are in opposition and the instability can occur. The kind of motion expected is indicated in figure 7 where accumulated charges instigate material flow which disturbs the director pattern as shown. Such a director pattern might be expected to produce stripes of the desired periodicity (~ cell thickness) since upward flow should show different optical properties from downward flow. Figure 7 shows the behaviour when many stripes are present. The initial stripes of figure 5 might be associated with a pair of vortices.

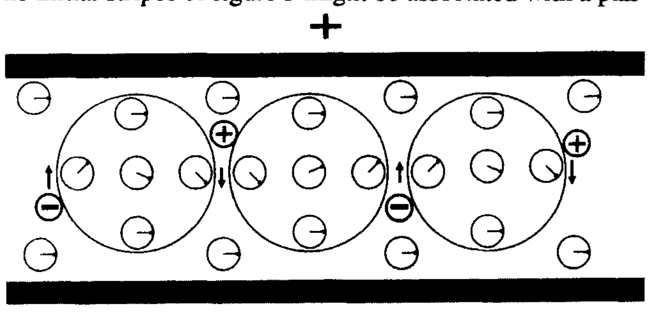

FIGURE 7 Possible flow pattern and Director Arrangement in SmC*

A further inducement to electrohydrodynamic flow is indicated in figure 8 where the chevron structure is shown. In the field off state all the directors lie parallel with the cell walls.

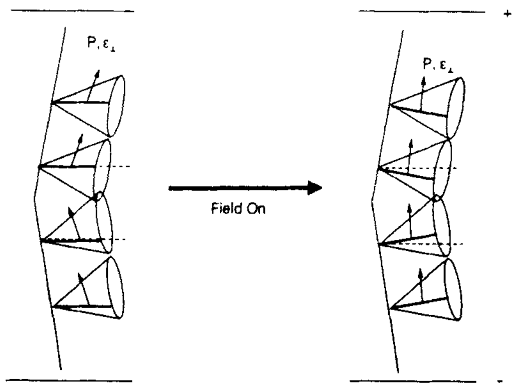

FIGURE 8 SmC*: Chevron showing out-of-plane tilt when field is applied. On applying a DC field the polarisation P and $\varepsilon_\perp$ line up with the field thus giving an out of plane tilt to the directors. This gives a contribution from $\sigma_\parallel$ to the conductivity across the cell which will act to nucleate charge separation in the Carr-Helfrich model. Of course when quasi-bookshelf geometry is achieved this nucleation will cease. The case of naphthalene-based materials which do not show a striped texture under conditions where it might be expected to form suggest that a chevron structure may be essential to its formation[11].

The charge separation for SmA is also associated with periodic layer bending under high fields for homeotropic alignment (e.g. ref 10 p.271). Whether a similar layer bending occurs with the chevron structure of SmC is not clear. To account for the observed periodicity it will therefore be necessary to invoke thermal fluctuations as a means to induce charge separation as has been done for nematics.

Corroborative evidence that sufficient ions were present to allow electrohydrodynamic instabilities was obtained by investigating the chiral nematic phases of the mixtures used. All were found to form domains associated with electrohydrodynamic instabilities. Concerning cell thickness: cell thicknesses down to 2.2μm showed broken domains in the nematic phase of ZLI-4655-100. For cells thinner than 1μm we have only observed small patches of domain-like features with turbulent (scattering) electrohydrodynamic effects predominating in the nematic phase at frequencies usually greater than 1kHz. This appears to contradict results of ref.10 (pages 192-194) where thin cells are not expected to show electrohydrodynamic effects. Alternatively it implies a high conductivity in our samples.

Racemic materials show striped textures very readily at low voltages. It therefore appears that the change of torque balance associated with the high Ps of materials showing the higher voltage threshold is needed to trigger their qualitatively different behaviour.

CONCLUSIONS

We have presented some data and a model for the formation of the striped texture in SmC* liquid crystals with high Ps (>10 $nC.cm^{-2}$).

We have indicated that electrohydrodynamic instabilities as the source of the striped texture and the formation of quasi-bookshelf geometry in SmC* in low frequency fields are as plausible and, for some observations, more plausible than the geometric field effect model of Shao et al[1].

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