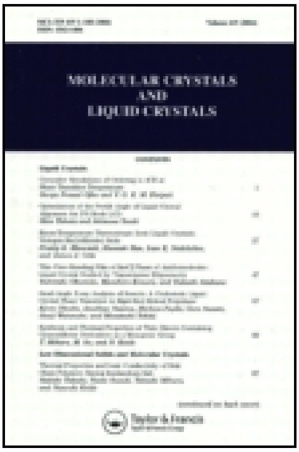

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Electrohydrodynamic Instabilities in Long Pitch Ferroelectric Sc* Liquid Crystals

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Electrohydrodynamic Instabilities in Long Pitch Ferroelectric Sc* Liquid Crystals

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In this paper, experimental investigations are reported on the unwinding process of a planar long pitch S_C^* phase under DC and AC electric fields. The investigations are carried out on a cell with a spacing of 50 μm. The DC critical fields (E_{dc}) for unwinding the helical texture are measured at different temperatures. Three patterns of electrohydrodynamic instabilities are found to exist under AC electric fields.

Keywords: Ferroelectric liquid crystal, long pitch, electrohydrodynamic instabilities, chiral smectic C.

INTRODUCTION

Since the discovery of ferroelectricity in chiral smectic liquid crystals in 1974[1] and the invention of an electro-optic effect in a surface-stabilized device in 1980,[2] both basic and applied researches of ferroelectric liquid crystals have accelerated.

Electrohydrodynamic instabilities induced by an AC electric field are well known in various liquid crystal phases. In nematic phases, the basic mechanism is now well understood in terms of the Carr-Helfrich model.[3,4] Helfrich made derivations only for the DC field which were further extended to AC fields by Dubois-Violette, De Gennes and Parodi.[5] Electrohydrodynamic instabilities in planar cholesteric texture leading to the periodic grid type have been reported in both negative and positive dielectric anisotropy materials.[6,7] Later on, these phenomena were also studied for the S_A phase, the S_C[8–10] phase and the S_C^* phase as well.

In the S_C^* phase, some new patterns of electrohydrodynamic instabilities were observed.[11–13] It was pointed out that the formation mechanisms are related to the conductivity, the spontaneous polarization and the dielectric properties of the ferroelectric liquid crystals.[14] Since the pitch is also an important parameter of the ferroelectric liquid crystals, we would like to know whether the length of the pitch has an effect on the patterns of instabilities. So far, the work on instabilities has only been performed in S_C^* phase with a relatively short pitch ($P = 3$–$5\,\mu$m). In this paper, we report the experimental results on electrohydrodynamic instabilities in the S_C^* phase with a long pitch ($P = 25\,\mu$m).

EXPERIMENTAL

The FLC material ZLI-5014-100 is kindly supplied by E. Merck. The mesomorphic phase sequence is as follows:

$$C < -10\,^\circ C \quad S_C^* \quad 65\,^\circ\mathrm{C} \quad S_A \quad 70\,^\circ\mathrm{C} \quad Ch \quad 72\,^\circ\mathrm{C} \quad I$$

The pitch, the spontaneous polarization and the dielectric constant at 20 °C are $p = 10\,\mu\mathrm{m}$, $Ps = -20.0\,\mathrm{nC/cm^2}$ and $\Delta\varepsilon = -1.2$ (7.5 kHz driving voltage at 20 °C) respectively. The sample cell consists of two glass plates coated with ITO electrodes and polyimide aligning films. The cell spacing is 50 μm. The rubbing directions on two glass surfaces are parallel. The cell is placed in a Mettler hot stage FP82 with a temperature control of 0.1 °C, and set under an Olympus polarizing microscope. The liquid crystal is heated to the isotropic phase and injected into the cell under the action of capillary force. Then the sample cell is cooled down at the rate of 0.1 °C/min from the isotropic phase to the S_A phase under an AC electric field of 0.002 v/μm with $f = 20$ Hz. Further cooling without the action of the field results in a well aligned planar texture of the S_C^* phase. All measurements are performed at $T - Tc = -5\,^\circ\mathrm{C}$ ($Tc = 65\,^\circ\mathrm{C}$, the transition temperature between the S_A and the S_C^* phases).

RESULTS AND DISCUSSION

In absence of the field, we see parallel stripes which are perpendicular to the original rubbing directions. The stripe spacing is the pitch of the helical texture (Fig. 1), which is 25 μm at 60 °C. The pitch increases with an increase of the DC electric field. Under

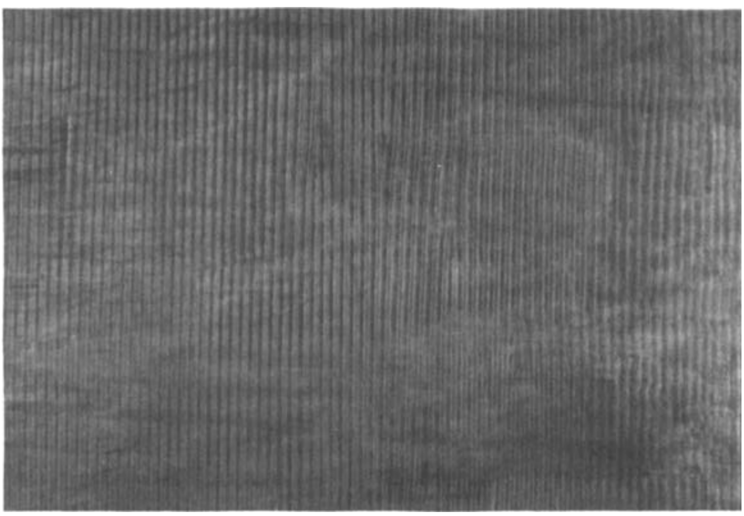

FIGURE 1 Texture of a well aligned planar S_C^* sample in the 50 μm cell. The stripe spacing is equal to the helical pitch, $P = 25\,\mu\mathrm{m}$ at 60 °C. (magnification 188x). See Color Plate II.

a large enough DC field, the stripes disappear. This field is called the DC unwinding critical field (E_{dc}), which is the function of temperatures (Fig. 2).

Sinusoidal voltages are applied to the cell of 50 μm with the effective voltage up to 98.8 v and the frequency up to 10 kHz. The electro-optic response is measured under a polarizing microscope in transmission. Three different ranges of electro-optic responses are discerned, depending on both the applied voltage and the frequency.

In the low frequency region (up to 20 Hz), an AC field can couple with *Ps*, unwinding the helical structure like a DC field. The dechiralization lines show a periodic shift in the direction of the helical axis. This is in good agreement with the observations in the literature.[15] Above E_{ac} (the AC unwinding critical field), the parallel stripes disappear.

In the region of $f = 20$–5000 Hz, at a certain threshold voltage, the straight pitch stripes become undulation waves as indicated in Figure 3. The curve (*a*) in Figure 4 represents the frequency dependence of E_W (E_W is defined as the undulation wave threshold). This pattern exists until E increases up to E_{ac}. Near the E_{ac}, the distortion of the undulation waves becomes more serious and simultaneously the line spacing becomes large. The curve (*b*) in Figure 4 shows the frequency dependence of E_{ac}. Above E_{ac}, the parallel stripes disappear. With an increase of the field, above E_1 (E_1 represents the rhombic lattice threshold), the unwinding texture evolves into a rhombic lattice pattern (Fig. 5). The curve (*c*) in Figure 4 gives the frequency dependence of E_1. Upon a further increase of the field, some local rhombic lattice patterns change into λ-patterns (Fig. 6). These two instabilities are visible as periodic patterns of disclination lines which are observed in two directions with a 135° angle between them. The rubbing direction bisects the obtuse angle between these two directions (see Figs. 5 and 6), the directions for the stripes being in good accordance with the ones in the literature.[16]

In the region of $f = 5000$ Hz–10 kHz, with an increase of the field, the straight pitch stripes change to undulation waves. Above E_{ac}, the pitch stripes disappear and no regular pattern forms.

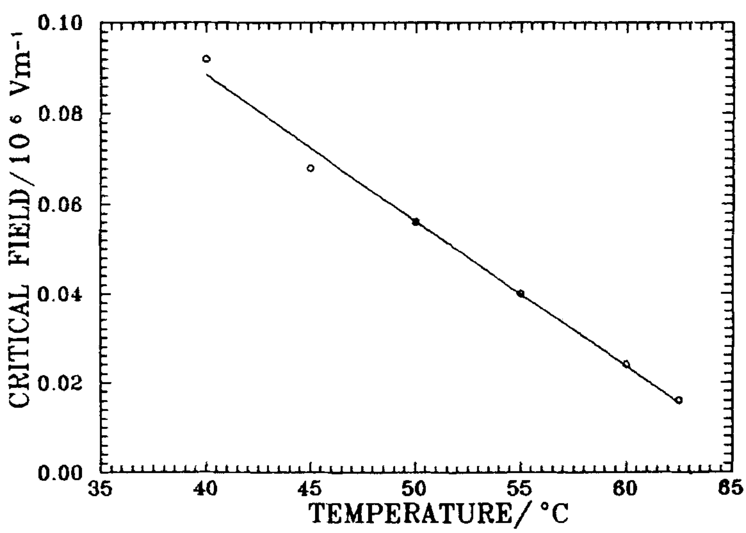

FIGURE 2 Temperature dependence of the DC critical field in the 50 μm cell.

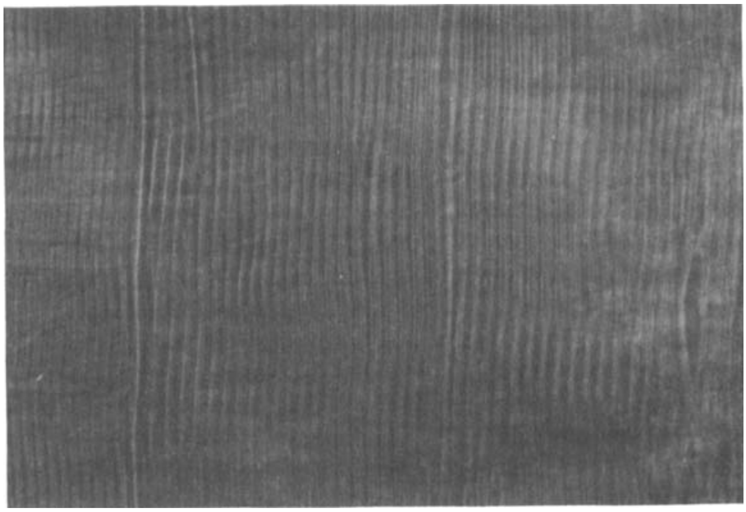

FIGURE 3 Undulation waves in the 50 μm cell, at 60°C under application of a 500 Hz AC voltage at 7.07 v effective value. (magnification 188x). See Color Plate III.

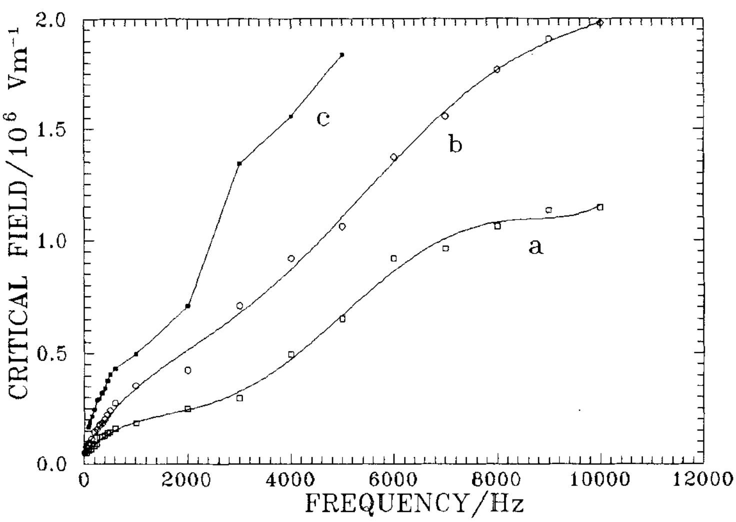

FIGURE 4 Frequency dependence of the various threshold fields and the unwinding critical field under an AC electric field.

It is noted that the curves (a), (b) and (c) in Figure 4 rise monotonically with an increase of the frequency, which indicates that the distortion of the helix becomes more and more difficult with an increase of the frequency. The variation of E_{ac} as a function of frequency is much more simple than that reported in the literature.[11,13] E_{ac} changes little between 0–20 Hz. This fact indicates that permanent polarization can follow the

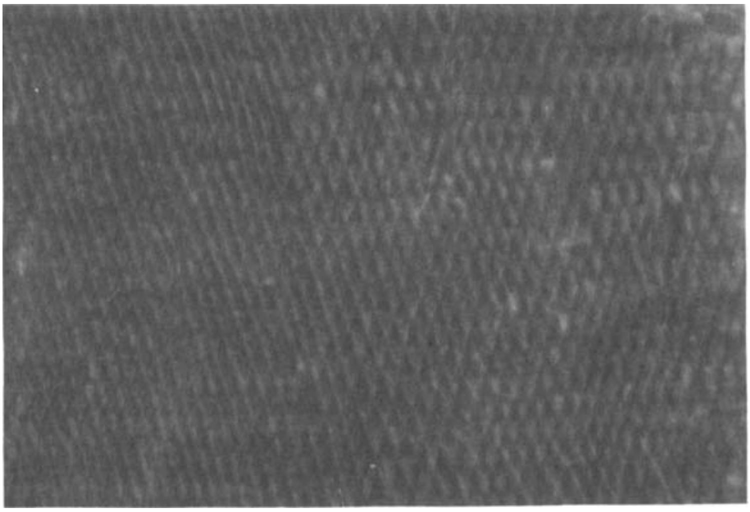

FIGURE 5 Rhombic lattice patterns above E_1 for the 50 μm cell, effective voltage = 19.8 v, f = 500 Hz. (magnification 188x). See Color Plate IV.

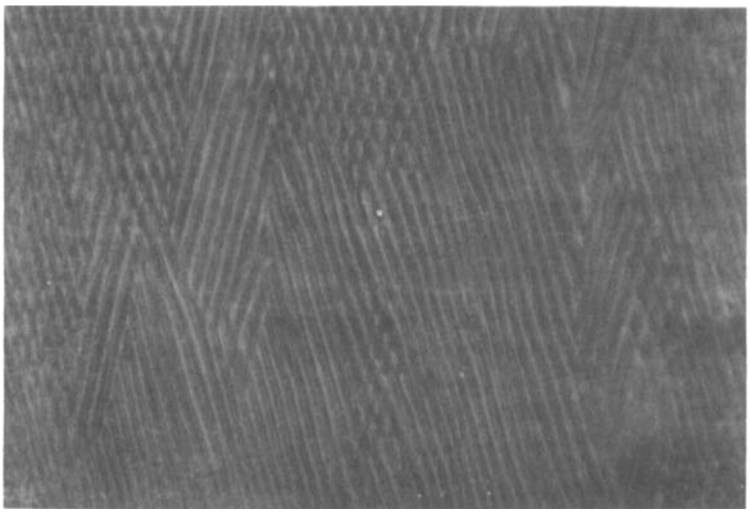

FIGURE 6 λ-Patterns and rhombic lattice patterns coexist above E_1 for the 50 μm cell, effective voltage = 24.75 v, f = 500 Hz. With an increase of the field, the local rhombic lattice patterns will all be replaced by the λ-patterns. (magnification 188x). See Color Plate V.

low frequencies and this zone pertains to the ferroelectric regime. E_{ac} tends to saturate at high frequencies. In the total region of frequency, we have not found a special frequency at which E_{ac} has a minimum value. This fact is different from the result obtained by Antal Jakli in FK4[11] and Z. H. Wang *et al.*, in FCS101.[13] The difference seems attributable to the relatively large pitch of ZLI-5014-100. Comparing the patterns of electrohydrodynamic instabilities in the short pitch FLCs[11–13] with those in the long pitch FLC, we can find that the undulation waves exist below AC critical field in both short and long pitch FLCs; the rhombic lattices and λ-patterns appear above the AC critical field in the long pitch FLC, while the similar patterns are observed below the AC critical field in the short pitch FLCs.[11–13]

CONCLUSION

In this paper, the unwinding process of a planar long pitch S_C^* phase under DC and AC fields has been investigated. Three different types of instabilities can be observed under the AC field. The instabilities below the critical field in the ZLI-5014-100 sample cell of 50 μm are undulation waves. Above E_{ac}, two patterns can be discerned at certain frequencies. They are rhombic lattices and λ-patterns. It seems that the long pitch has no much influence on the patterns of electrohydrodynamic instabilities in S_C^* phase.

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