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TEXTURES OF PLANAR ORIENTED FERROELECTRIC LIQUID CRYSTALS IN ALTERNATING ELECTRIC FIELDS

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Abstract We investigated the behaviour of thick chiral smectic C^* samples subjected to an alternating electric field. Various patterns of electrohydrodynamic instabilities have been observed below the unwinding threshold. A resonance-like minimum has been found in the frequency response which is connected with the conductivity of the substance.

INTRODUCTION

The chiral smectic C^* (S_C^*) phases of liquid crystals show a number of fascinating properties. They are ferroelectric which fact gives rise to linear electromechanical[1-2] and electrooptical[3-4] effects. This latter phenomenon makes them potentially attractive for application in high speed switching devices.

In this paper we report on our investigations of the textures of planar oriented ferroelectric liquid crystals under the influence of various electric fields (the amplitude varies from zero up to the critical unwinding one, and the frequency varies from DC up to 2 kHz).

The measurements were carried out on samples with different, relatively large conductivities.

EXPERIMENTAL

The electrooptical behaviour of sandwich cells were investigated by a microscope. The planar orientation of the samples were established by a special shear method.[5] The homogeneity of the samples was sufficiently good (see Fig.1). In the samples there were regions with a diameter about 200-300 μm which were perfectly aligned with their smectic layers in one direction, but the difference between the directions of the smectic layer normal in the neighbouring regions did not exceed 5^{0}. This small difference in directions may be due to the uncertainty of the shearing direction and the presence of dust particles.

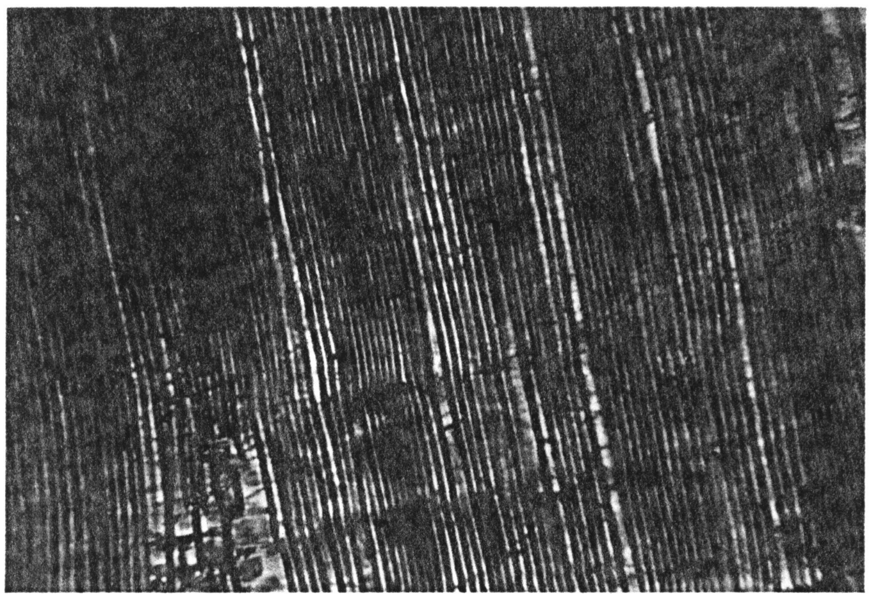


FIGURE 1 Picture of a planar oriented S_C^* sample (0.5x0.3 mm^2). The stripes are parallel to the smectic layers. The distance between two neighbouring stripes is equal to the helical pitch p=5μm. See Color Plate VIII.

If the sample thickness is higher than the pitch, a sequence of parallel straight stripes can be seen with and without polarisers. These stripes correspond to the dechiralization lines[6].

One of the main goal of our measurements was to investigate the behaviour of these stripes under various alternating electric fields. For this purpose we used a liquid crystal binary mixture FK4 with the phase sequence[7]:

$$S_I^* \xrightarrow{16^oC} S_C^* \xrightarrow{29^oC} S_A \xrightarrow{63^oC} Ch \xrightarrow{67^oC} I$$

The pitch and the spontaneous polarization at $T=23^oC$ were $p=5\mu m$ and $P=10^{-5}$ C/m^2 respectively.

For the quantitative measurements two samples were used. Sample A had a thickness of 60 ± 2 μm and an average conductivity of $\sigma=10^{-7}$ $(\Omega m)^{-1}$ while sample B had a thickness of 40 ± 2 μm and an average conductivity of $\sigma=7\times10^{-9}$ $(\Omega m)^{-1}$. The average dielectric permittivity in both samples were $\varepsilon=4.5$.

The qualitative behaviour of both samples were very similar.

In the low frequency region (below 5 Hz) a periodic shift of the dechiralization lines in the direction of the helical axis can be observed with the frequency of the applied field. This sideward shift was explained earlier by Glogarova et al[6].

The amplitude of this displacement of lines increases with the amplitude of the electric field, except at the walls where domains with slightly different layer normals join together.At these walls the lines are pinned up yielding a bended stripe structure. Increasing the electric field further the continuous but bended stripes begin to split and reaching up a certain electric field all the stripes disappear. This field is called as the unwinding critical field E_C.

In the high frequency region (above 10 Hz) one can see the following structures:

a. At low field amplitudes the parallel stripes are in rest.

b. At a certain threshold field E_{th} an undulation instability occurs, the straight stripes become sinusoidally distorted with a wavelength which is in the order of the width of the monodomains.

c. Above E_{th} the pure sinusoidal pattern varies and forms a zig-zag structure[8].

d. Increasing the field the wavelength decreases and simultaneously the line width becomes narrower.

e. Increasing the amplitude of the field further this zig-zag structure becomes unstable and at the unwinding critical field E_C the stripes disappear.

This type of structure-morphology is shown in Fig.2 at f=10Hz.

We measured the frequency dependence of the unwinding critical field in both samples (Fig.3). Due to inhomogeneities in the sample thickness E_C varies in the sample. This variation was found to be less than 10%, however during our measurements we always observed the same area to avoid this uncertainty.

Disregarding the frequency interval around f_{min} the curves are very similar to each other and the one measured by us on FK4 sample with a lower conductivity ($\sigma \leqq 10^{-10}$ $(\Omega m)^{-1}$)[7].

The sharp increase of the threshold field in the frequency interval 5-10Hz is due to the different unwinding mechanism in the low and high frequency regions.[9] At high frequencies the spontaneous polarization can not

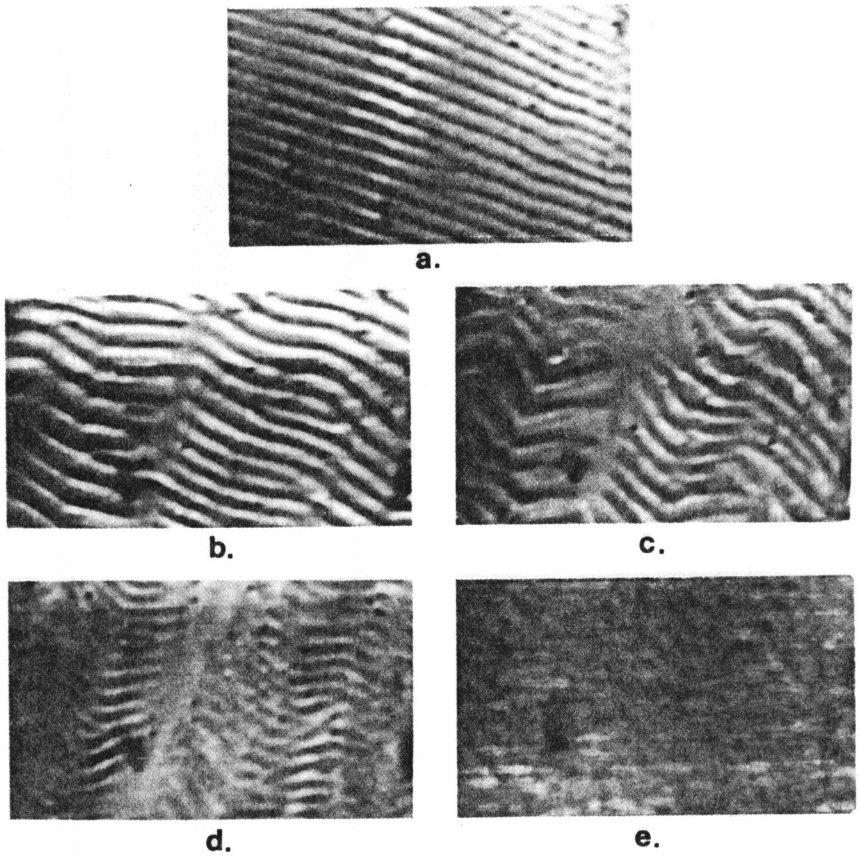


FIGURE 2 Textures of sample B under the influence of AC electric field (f=10Hz, $T=22^{O}C$). The distance between the stripes corresponds to the pitch p=5μm.

a. $E=10^5$ V/m: the parallel straight stripes are in rest up to a threshold amplitude $E_{th}=3\times10^5$ V/m.

b. $E=3.5\times10^5$ V/m:sinusoidal undulation instability with a wavelength λ=50 um.

c. $E=6\times10^5$ V/m zig-zag structure.

d. $E=9\times10^5$ V/m: perturbed zig-zag structure.

e. $E=2\times10^6$ V/m: unwound homogeneous structure. (The unwinding critical field is $E_C=1.9\times10^6$ V/m.)

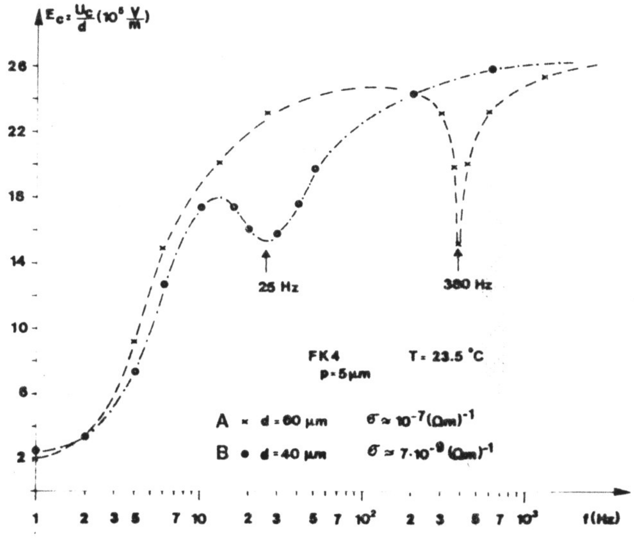


FIGURE 3 Frequency dependence of the unwinding critical field E_C for two samples of FK4 at $T=23.5^{o}C$. Both curves show a minimum at a frequenc $f_{min}=380Hz$ for sample A and $f_{min}=25Hz$ for sample B

follow the electric field hence at low frequencies the ferroelectric while at high frequencies the dielectric interaction will unwind the helix.

It can be seen in Fig.3 that there is a resonance-like minimum on both curves(at $f_{min}=380Hz$ on sample A a at $f_{min}=25Hz$ on sample B).

From the resistance R and capacitance C of our samples can calculate their characteristic frequencies f_{RC} whic are independent of the sample geometry:

$$f_{RC} = 1/(2\pi RC) = \sigma/(2\pi\varepsilon\varepsilon_0) \qquad (1)$$

From the measured impedances we obtained:

f_{RC} = 360Hz for sample A and

f_{RC} = 25Hz for sample B.

Thus, taking into account the measuring errors of capacitance, resistance and the unwinding critical field, we conclude that

$$f_{RC} = f_{min} \quad (2)$$

for both samples.

This identity suggests that the resonance-like minimum in the frequency response is connected with the conductivity of the samples.

At frequencies near to f_{min} the unwinding mechanism is different from the one described above. In the microscope one can see that at E_C a real flow starts in the direction of the layer normal with a spatial periodicity equal to that of the zig-zag structure (Fig.4). This flow makes the zig-zag stripes tear and move out in opposite directions yielding an unwound texture. (A similar mechanism was described by Labroo et al.[10] in focal conic S_C^* samples.)

We have also observed that in the vicinity of f_{min} the time necessary for the stripes to disappear varies very seriously with the applied voltage and the temperature as shown in Figs.5 and 6 for sample A. From Figs.5 and 6 the following relations can be deduced:

$$\log t \sim 1/(T-T_{th}(U)) \quad (3)$$

and

$$\log t \sim 1/(U-U_{th}(T)) \quad (4)$$

Since the velocity of flow is inversely proportional to the time necessary for the total unwinding in a certain area of the sample one can obtain from Eqs.(3) and (4) for the flow velocity that:

$$v \sim \exp(-1/(T-T_{th}(U))) \quad (5)$$

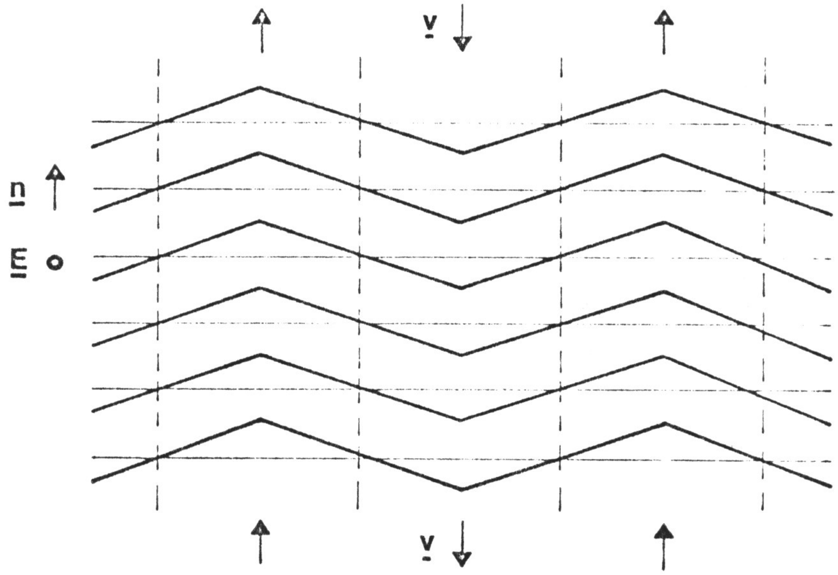


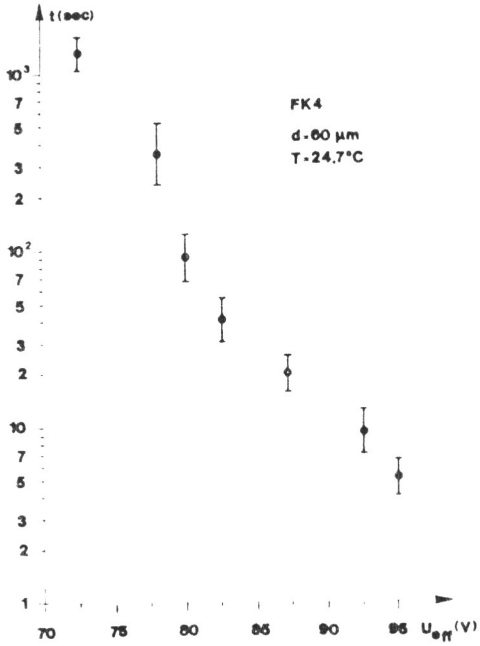
FIGURE 4 Schematic representation of the flow induced by an electric field E of a frequency f_{min}. The direction of the flow is parallel to the smectic layer normal n.

and

$$v \sim \exp(-1/(U-U_{th}(T))) \qquad (6)$$

These proportionalities confirm that the flow is induced by the electric voltage which has a threshold value. This threshold behaviour indicates that some energy is needed to stear up the dechiralization lines. Equation (5) shows that this energy increases with decreasing temperature.

Equation (6) is in good agreement with the measurement of Labroo et al.[10] Furthermore, estimating the absolute value of velocities from the diameter of the observed area (0.5 mm) we obtained that the maximal value



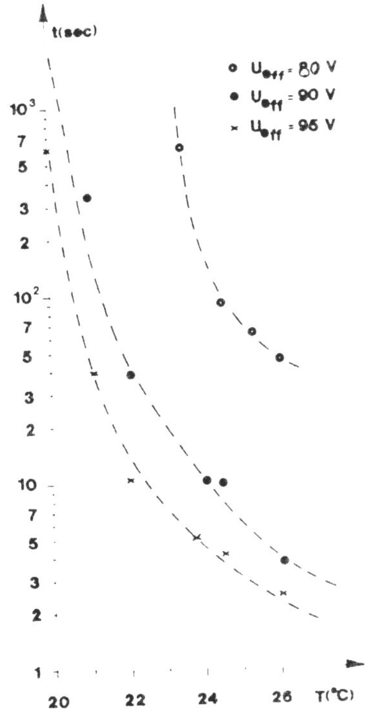


FIGURE 5(on the left) The time of the total unwinding versus applied electric voltage for sample A at f_{min}=380Hz and T=24.7^{0}C.

FIGURE 6(on the right) Temperature dependence of the time of the total unwinding for sample A at f_{min}=380Hz at different applied voltages.

of flow velocity at U_{eff}=95V is v=0.25mm/s which is in the same order as the one (v=0.2mm/s) reported for DOBAMBC[10].

We still have to explain the absence of minima in the frequency dependence of the unwinding critical field in earlier measurements.[7,9] In case of the FK4 sample with low conductivity[7] the characteristic frequency is $f_{RC} \leqq 1Hz$. At this low frequency, however the unwinding mechanism due to the ferroelectric coupling is stronger than the one due to the flow thus the latter mechanism is ineffective. The same arguments are valid for the measurement on DOBAMBC[9].

The detailed description of the possible mechanism of unwinding around f_{RC} will be presented in a subsequent paper within the framework of a theoretical model which is capable to explain the appearence of sinusoidal distortions as well as zig-zag structures.

Similar zig-zag structures can be observed under other circumstances as well.

It is known that if we unwind the structure by a sufficiently high electric field,removing the field the original sequence of the straight dechiralization lines reappears very slowly. Generally it lasts more than several minutes. However, if we apply such an electric field that would distort the parallel stripes to a zig-zag structure, a zig-zag structure developes also from the unwound state quickly in several seconds. The distance between the stripes were found to be in the order of the pitch.

Similar patterns were found in various surface stabilized samples too. These instabilities remind us of the so called "fundamental domains" which were observed by Petroff et al.[11] in nonchiral smectic C phases.In fact this similarity is not surprising,because the structure of an unwound chiral S_C^* phase is almost the same as that of a nonchiral S_C phase.

It suggests that the electrohydrodynamic instabilities in S_C and unwound or surface stabilized S_C^* samples may develop by a common mechanism.

SUMMARY

We investigated the behaviour of planar oriented S_C^* liquid crystals in electric fields.

In thick samples (the sample thickness is larger than the pitch) we observed that at electric fields larger than a certain threshold one E_{th}, but less than the unwinding critical field E_C, an undulation instability of the originally straight parallel stripes occurs.

At fields near to the threshold ($E \gtrsim E_{th}$) the distortion of the stripes is sinusoidal which tends to have a zig-zag shape at higher fields.

A minimum was observed in the frequency dependence of the unwinding critical field E_C. The minimum in the frequency response coincides with the characteristic frequency of the substance. In the vicinity of this frequency the unwinding takes place by a flow.

Similar electrohydrodynamic instabilities were observed on unwound thick samples and on surface stabilized chiral smectic C samples too.

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