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Electroconvective Instabilities in Freely Suspended and Bound Nematic Layers

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ELECTROCONVECTIVE INSTABILITIES IN FREELY SUSPENDED AND BOUND NEMATIC LAYERS

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Abstract EHD effects are studied in high conductivity MBBA layers aligned homeotropically with respect to all the interfaces. Both freely suspended and bound films are examined under ac fields acting transversely to the line of sight. The orientational distortion originates as two periodic waves close to the electrodes. The pattern symmetry is determined by their relative phase. For freely suspended films, both inphase and 180° out of phase waves occur; the domains are non-centrosymmetric in the former case, and centrosymmetric in the latter. For bound films, only the in phase waves occur; further, close to the frequency cut-off, two oppositely drifting wave trains appear along the electrodes.

INTRODUCTION

When the director in a rectangular nematic slab is normal to the limiting surfaces, a -½ disclination loop forms in the vicinity of lateral boundaries and around the central pseudoisotropic zone. In this configuration, under ac driving, several interesting non-linear distortion phenomena are observed. In our recent reports[1,2] concerning an orientational transition between two distorted states, we have discussed some of these. We characterize here the sequence of homogeneous stationary states on the route to turbulence in both open and bound nematic samples.

EXPERIMENTAL

The MBBA sample had an electrical conductivity of ~ 0.01 μS/cm, corresponding to a cut-off frequency of ~7.5 kHz. The director configuration, derived spontaneously, is shown in Figure 1. Freely suspended films were formed between the edges of 100 μm thick stainless steel electrodes. Bound samples were held between glass plates separated by 70 μm thick copper electrode spacers. Observations were made along Z, transversely to the electric field along Y, under a CZ microscope, in transmitted light. For

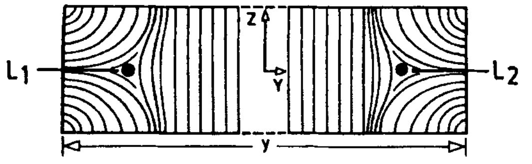

FIGURE 1 Initial director configuration. Electric field along Y.

interference studies, mercury green light was used. Further experimental details are found in our previous reports.[1,2]

RESULTS AND DISCUSSION

Low Frequency Instabilities in Freely Suspended Films

The sample texture in the field free state is reproduced in Figure 2a. Birefringence bands near the two electrodes are due to splay-bend deformations associated with the disclinations L_1 and L_2 (Figure 1). Under a progressively increasing field the first

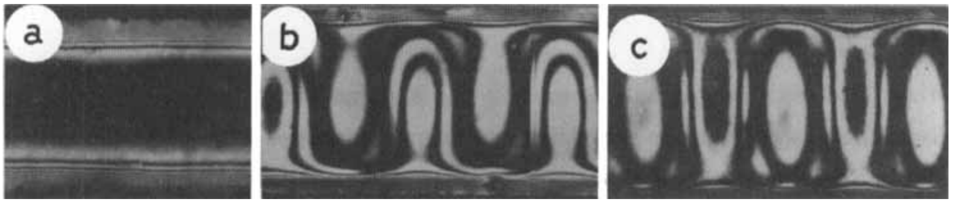

FIGURE 2 Textures for crossed polarizers in the diagonal position. (a) Field off state. (b) Non-centrosymmetric domains. (c) Centrosymmetric domains.

bifurcation into the EHD state occurs at a well marked voltage threshold V_{th}. The bands near L_1 and L_2 then turn wavy. The two distortion waves along the disclinations are either inphase or 180° out of phase. Above V_{th}, the waves develop toward the opposite electrodes from regions D in Figure 3. Even as the distortions reach the sample midregion, new centres of instability develop periodically between the opposite extrema of distortion waves (C_1, C_2 ..., Figure 3). Figures 2b and 2c depict the texture at this stage. The pattern symmetry is dependent on the relative phase of the initial distortion waves. For the inphase mode, the domains are non-centrosymmetric; for the out of phase mode, they are centrosymmetric.

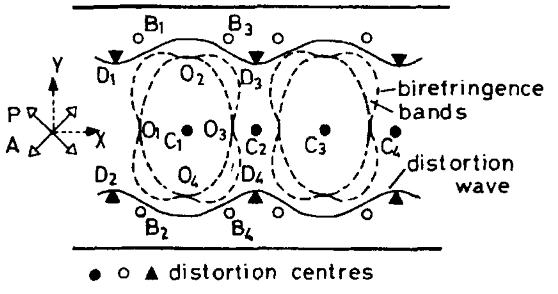

FIGURE 3 Schematic representation of the 180° out of phase distortion waves and the various centres of instability.

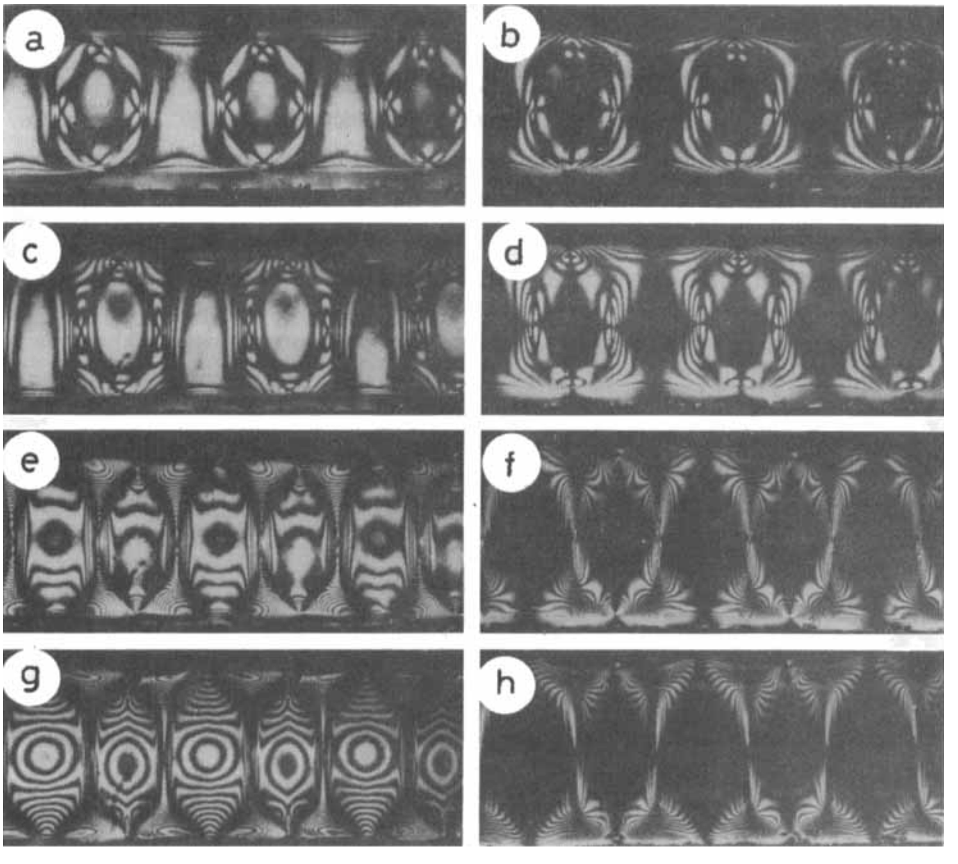

FIGURE 4 Low frequency Patterns. Crossed polarizers in the diagonal position for textures on the left, and along the figure-edges for textures on the right. 210 Hz. 25 °C. ~ 460 μm wide and ~ 70 μm thick sample. Voltages are 8.3, 12.4, 19.7 and 35.7 from top to bottom.

For further characterization, we confine to the 180° out of phase mode (Figure 4). Simultaneous development of distortions from C and D centres results in extinctions at locations O. The director remains undeviated at O, throughout the state of stationary structures. The director field around O_1, O_3... corresponds to that of a +1 line defect; that around O_2, O_4..., to that of a -1 defect (Figure 7, Reference 3). In the central part of all the domains, the director deviations are confined to the YZ plane (Figure 4b).

In the third and final stage of development of instabilities, new centres of distortion B (Figure 3) appear periodically near the electrodes. These, and the centres D, become ever more prominent with rising voltage and determine the pattern symmetry well above V_{th} (Figures 4c-h). Accordingly, the order of interference is the lowest at the domain centres in Figures 4e and 4g. At even higher voltages, the director field becomes unstable and turbulence sets in.

High Frequency Instabilities in Freely Suspended Films

Figure 5 presents the patterns near the cut-off frequency, for the 180° out of phase mode. Clearly the peripheral distortion centres B (Figure 3) gain in dominance with frequency. Frequency variation of the electric field configuration could explain this effect. For the high frequency regime, the maximum field occurs near the electrodes and the minimum in the central zone. This is not the case in the low frequency regime

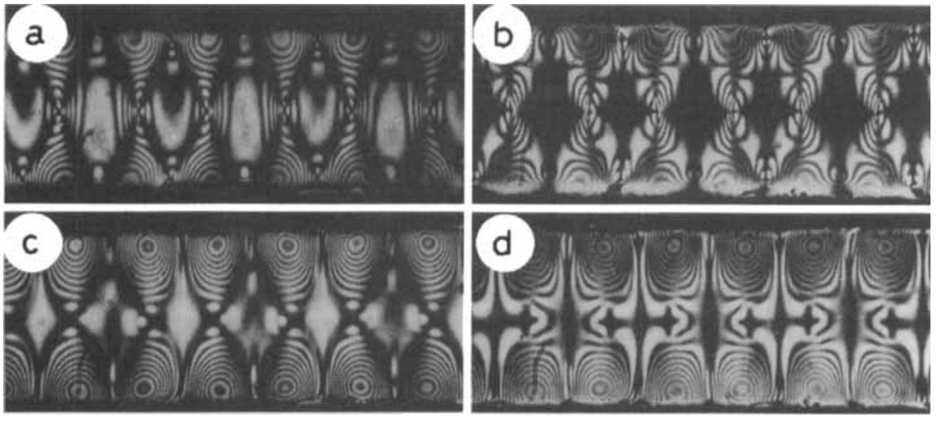

FIGURE 5 High frequency patterns. (a,b) 5 kHz, 26 V; (c,d) 7.2 kHz, 59 V. Other details as in Figure 4.

because of surface charges, as pointed out previously by Faetti et al.[4] The fringes in Figure 5d do not exhibit a good contrast mainly due to the optical activity in the domains around B. Figure 6 shows that the sense of rotation alternates for adjacent domains along X.

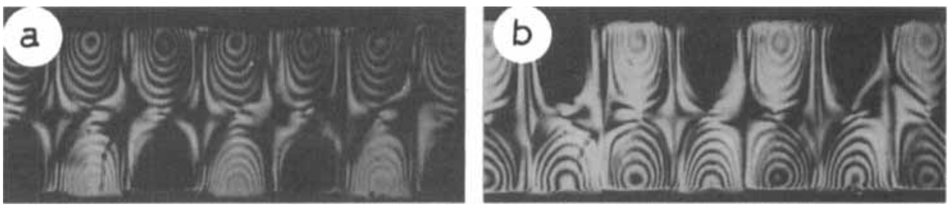

FIGURE 6 Optical activity developed at higher voltages and frequencies. (a) Analyser (A) along Y and polarizer (P) at 70° to X. For A along X and P at 20° to X, the contrast for lower domains reverses. (b) P along X and A at 30° to X. For P along X and A at 150° to X, the contrast for upper domains reverses. The overall rotation is 60 - 70°.

Instabilities in Bound Samples

The low frequency patterns have already been discussed earlier.[1,2,5-7] The patterns generally correspond to the in-phase mode. The centres of distortion C lie along a common line for one set of alternate domains and along another line for the other. These centre-lines separate more and more, moving toward opposite electrodes with increasing frequency (Figure 7), due to variations in the field intensity.

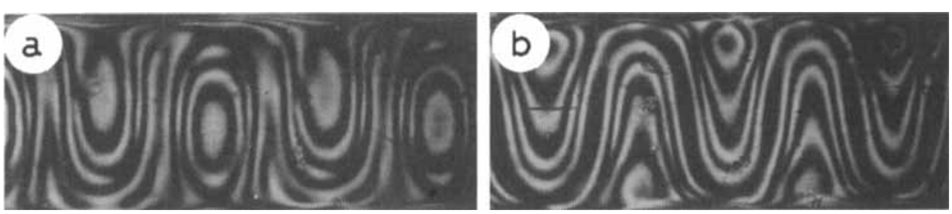

FIGURE 7 Frequency variation of texture for bound samples. (a) 20.5V, 500 Hz. (b) 25 V, 2.5 kHz. Crossed polarizers, diagonally set. 565 μm wide, 150 μm thick sample. 24 °C.

The Freedericksz threshold is lower than that for the EHD effect at higher frequencies. Thus the birefringence bands in the disclination zone recede toward the electrodes at lower voltages, but turn wavy and advance inward at higher voltages (Figure 8). Figure 8d shows a novel instability noticed on applying a 6.5 kHz, 100 V field. A succession of parabolic domains may be recognised along the electrode edges. These drift in opposite directions along X, at the rate of about 15 μm/s. A detailed investigation of this instability is underway.

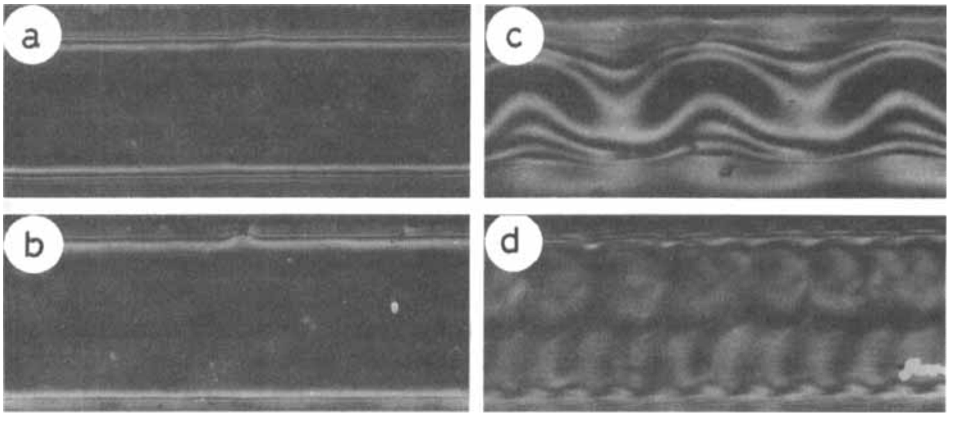

FIGURE 8 (a-c) Textures at 5.5 kHz, 0 V (a), 20 V (b) and 54 V (c). (d) Textures of travelling waves at 100V, 6.5 kHz. Other details as in Figure 7.

Hydrodynamic Flows

The flows for open films occur around regions O_1, O_3 ... (Figure 3), and in both lower and upper halves of the sample.. The circulation is in opposite senses for adjacent cells both along X and Z, as observed by Faetti et al.[4] For bound films, again the flows are centred around such locations as O_1, O_3... where the alignment is pseudoisotropic, but are confined to the sample midplane. Flow velocity data are already reported for low frequencies.[2] Within the conduction regime, increase in frequency amounts effectively to a decrease in field strength; otherwise the flow features show the same dependence on the control parameter.

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