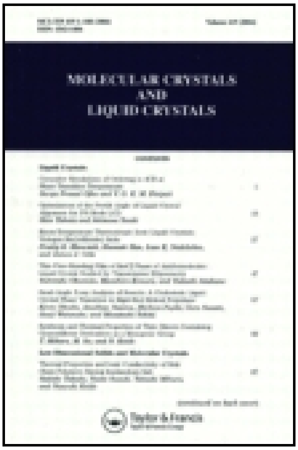

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl16

Some Microstructural Observations of MBBA Liquid Crystal Films

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Version of record first published: 28 Mar 2007.

To cite this article: Roger Chang (1973): Some Microstructural Observations of MBBA Liquid Crystal Films, Molecular Crystals and Liquid Crystals, 20:3-4, 267-278

To link to this article: http://dx.doi.org/10.1080/15421407308083048

Molecular Crystals and Liquid Crystals. 1973. Vol. 20, pp. 267–278

Some Microstructural Observations of MBBA Liquid Crystal Films

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Received August 14, 1972

Abstract—Microstructural changes of MBBA liquid crystal films are investigated where the direction of observation is perpendicular to the applied electric field (dc or low frequency ac) direction. Some unusual features are reported and possible mechanisms for the formation of Williams domains and the " dynamic scattering " state from the microstructural point of view are discussed.

1. Introduction

Studies of the formation of Williams domains and the " dynamic scattering " state of negative nematic liquid crystal films under dc or low-frequency ac electric fields have been reported by many investigators. In almost all instances the direction of observation and the applied electric field direction are parallel to each other. Williams[1] has recently discussed an experiment in which the line of sight is perpendicular to the applied electric field direction where the electrode spacing l is large compared to the film thickness $d(l/d > 1000)$. We describe here an experimental arrangement qualitatively similar to Williams' except that our l/d ratios are much smaller ($l/d < 10$). This experimental arrangement permitted us to investigate the formation of Williams domains and the " dynamic scattering " state in much greater structural detail than those reported in the literature.[2] We present here some unusual microstructural observations which may provide new information concerning the response of negative nematic liquid crystal films to applied electric fields under specified boundary (homogeneous or homeotropic†) conditions.

† According to Gray,[3] the homogeneous and homeotropic states of a nematic liquid crystal film are where the molecular axes (the directors) are, respectively, parallel and perpendicular to the film plane.

2. Experimental

The liquid crystal cell consisted of two flat glass plates separated by two parallel strips of aluminium foil about 50 μ thick and spaced 50 to 200 μ apart as electrodes, thus giving l/d ratios less than 5. The electrical field was applied across the aluminium electrodes in the film plane and perpenduicular to the line of sight. The liquid crystal filled the space between the aluminium electrodes and was examined with a Unitron U–11 microscope at 100 × to 1000 × under white transmitted light either with or without crossed polarizers.

Attempts to film-deposit aluminum electrodes were successful but the electrodes were too thin (of the order of 1000 Å) so additional mylar spacers were required which gave rise to very non-uniform electric field gradient across the thickness direction of the liquid crystal film.

Methoxybenzylidene butylaniline (MBBA), a room temperature negative nematic liquid crystal in both purified (by repeated distillations) and doped form, was used in this study. The nature of the ionic conductivity of doped MBBA was a subject of separate discussion appearing elsewhere.[4] The pictures presented in this study were taken mostly with Polaroid 3000 speed black and white and occasionally 75 speed colored roll film at either 185 × or 370 × as mentioned in the text.

3. Results and Discussion

For the convenience of presentation, the following types of microstructures are defined:

(1) The V structure is a homeotropically aligned structure where the liquid crystal directors are perpendicular to the film-plane and parallel to the line of sight. Under zero field the structure appears uniformly dark under crossed polarizers. In our cell configuration the applied electric field direction lies in the film-plane. The application of dc or low-frequency ac electric field rotates the directors towards the direction of the applied electric field, giving rise to color bands; this is called the V′ structure. Typical V and V′ structures are illustrated, respectively, in Figs. 7(a) and 7(b).

(2) The H structure is a homogeneously aligned structure where the

liquid crystal directors lie in the film-plane and perpendicular to the line of sight. Depending on the orientation of the directors, the structure can appear uniform (randomly oriented directors) or birefringent (unidirectionally oriented directors within a liquid crystal domain) under the microscope.

(3) The P structure is a specific type of point disclination[5] within the H structure and V′ structure.

(4) The B-boundary is the boundary structure joining the V or V′ and H structures. It appears as a band and is not resolvable in detail at 1000 × under the optical microscope. It is a line disclination separating domains of differently oriented directors of the liquid crystal molecules. Typical B structures are shown in Figs. 6(a) and 6(b).

(5) The spiked-structure is essentially the V′ structure generated at the glass–H structure interface under applied dc or low-frequency ac electric field. It is nucleated at the glass–H structure interface and grows into the H structure upon increasing field excitation. Typical examples of the spiked-structures are shown in Figs. 1(a) and 1(b).

Homogeneously Aligned Film Under Zero Field

Distilled and undoped MBBA (conductivity $<10^{-10}$ mho-cm^{-1}) film gives rise to Williams domains and the " dynamic scattering " state only under dc excitation. Figures 1(a) and 1(b) illustrate the formation of spiked V′ structures which grow into the original H structure at increasing applied dc electric field slightly above the Williams domain threshold. Details of such studies will be reported elsewhere,[2] suffice it to mention that in our experimental arrangement the Williams domain threshold voltage changes with the l/d ratio. Similar structures were observed of doped MBBA films under low-frequency ac excitation.

Figures 2(a) and 2(b) illustrate the microstructures of a doped MBBA film (conductivity 3.5×10^{-10} mho-cm^{-1}) under, respectively, 25 and 27 volts rms at 60 Hz where the zero-field structure is the H-type. Figures 3(a) and 3(b) are taken of another doped MBBA film under 45 V rms at 60 Hz. All four figures are grossly similar: H structure divided into cells by vertical bands of V′ structure and containing often a P structure near the cell center. The V′ bands are

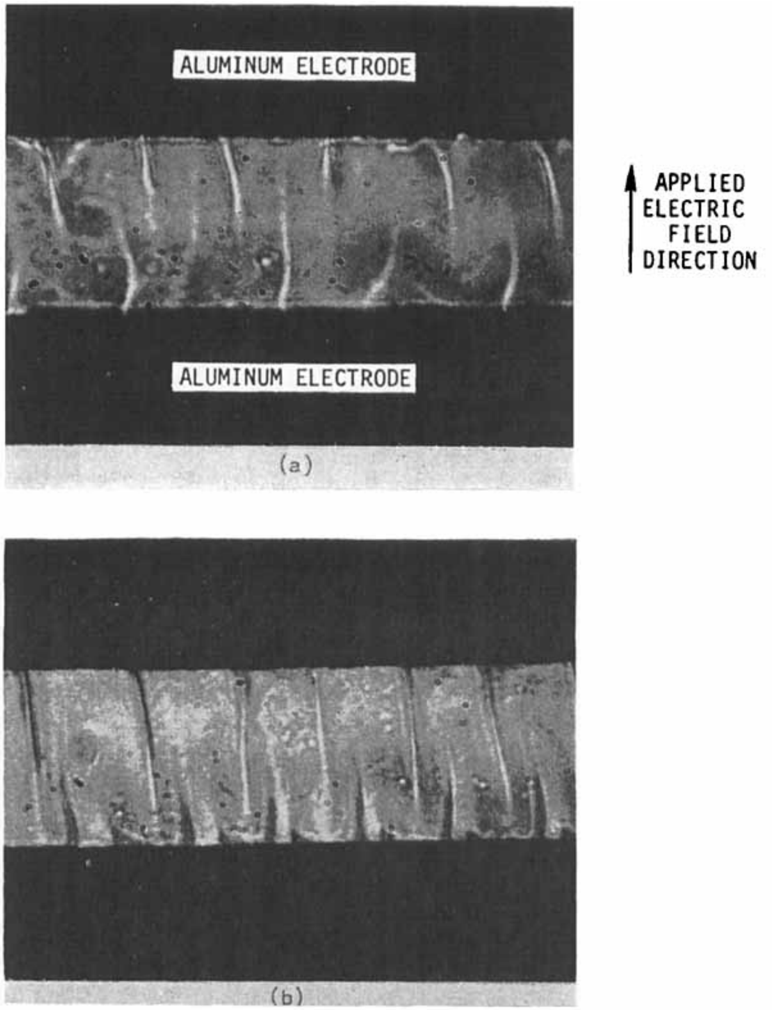


Figure 1. Transverse domain structure of distilled MBBA film (conductivity $<10^{-10}$ mho-cm^{-1}) under applied dc field near Williams domain threshold, 185 × (Fig. 1a, 20 V, Fig. 1(b), 25 V; $l/d \sim 3$), transmitted white light.

very mobile; they originate always at the electrode–H structure interface, speed across to the other electrode, sometimes remain, other times disappear entirely. When two such V′ bands move toward each other from opposite electrodes and collide head on, a P structure is formed. A P structure is also observed to form in the

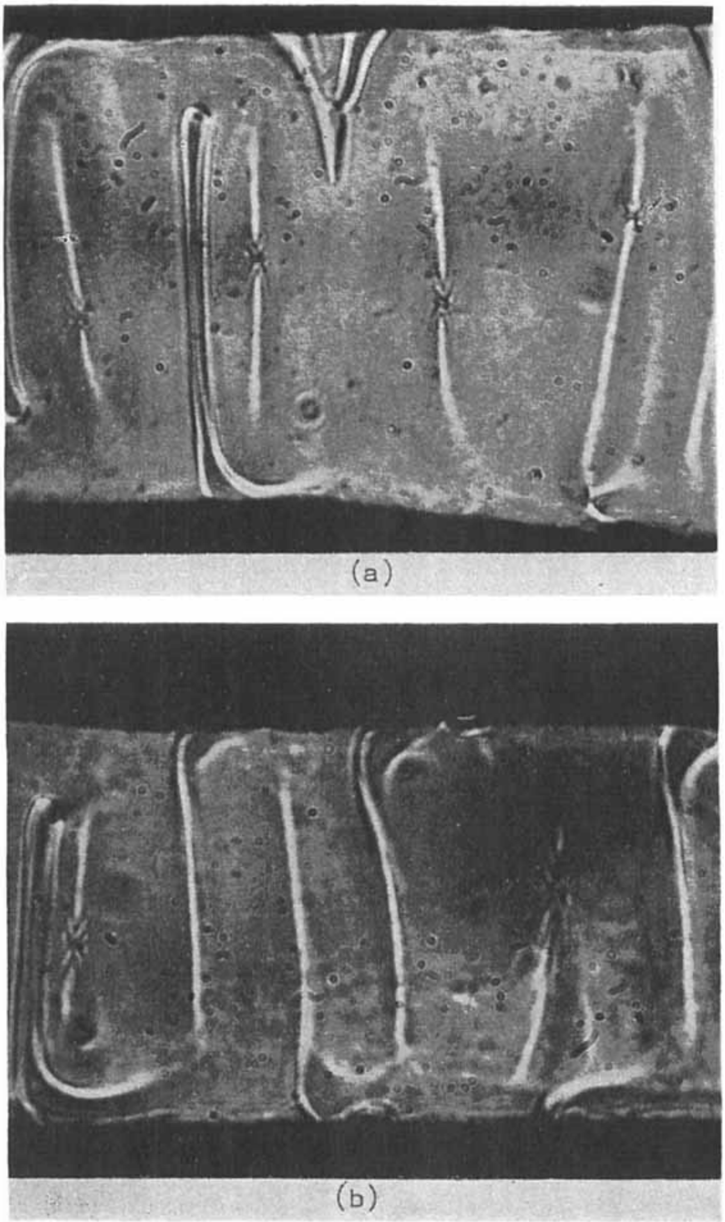


Figure 2. Transverse structure of doped MBBA film (conductivity 3.5×10^{-10} mho-cm^{-1}) under 60 Hz ac field beyond the Williams domain threshold, 370 ×, transmitted white light (Fig. 2a, 25 V rms; Fig. 2b, 27 V rms; $l/d \sim 3$).

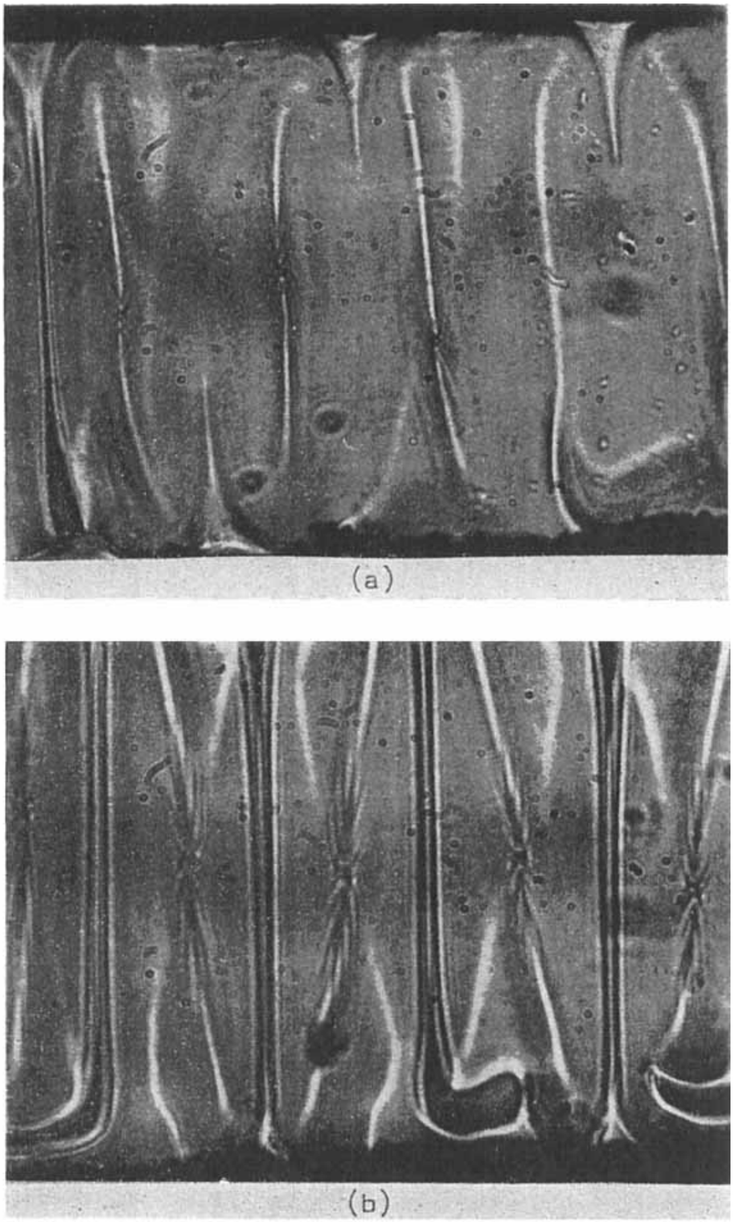


Figure 3. Transverse structure of doped MBBA film (conductivity 7×10^{-10} mho-cm^{-1}) under 60 Hz ac field beyond the Williams domain threshold, 370 ×, transmitted white light (Fig. 3a, 45 V rms; Fig. 3(b), 45 V rms; $l/d \sim 3.7$).

H structure when one of the crests of the moving B-type boundary (Figs. 6(a) and 6(b)) loops around a complete 360 degrees. These P structures are metastable structures and often remain in the H structure indefinitely after complete removal of the applied field, disappearing only by an approaching B-type boundary into the V structure. The central cell segment of Fig. 3(b) illustrates a dust cluster (dark region) rotating clockwise (at a speed of a few seconds per turn) around a P structure between the two V′ bands. It was occasionally observed that the dust cluster wandered into the neighboring cell segment and moved around another P structure in a counterclockwise fashion. These observations are in essential agreement with the experimental observations of Penz[6] except that we can watch the dust cluster in continuous motion. Motion of dust particles in cell segments without a P structure (see e.g., the center cell segments of Fig. 2(b)) was also observed.

An enlarged photograph of a P structure viewed with white transmitted light under crossed polarizers and zero field is shown in Fig. 4. The extinction cross indicates where the light propagates as pure ordinary or pure extraordinary waves where the optical axis at the P structure–liquid crystal interface is parallel to either the polarizer or the analyzer. The extinction crosses appear to be stable under the application of a small dc or low-frequency ac field, implying that the

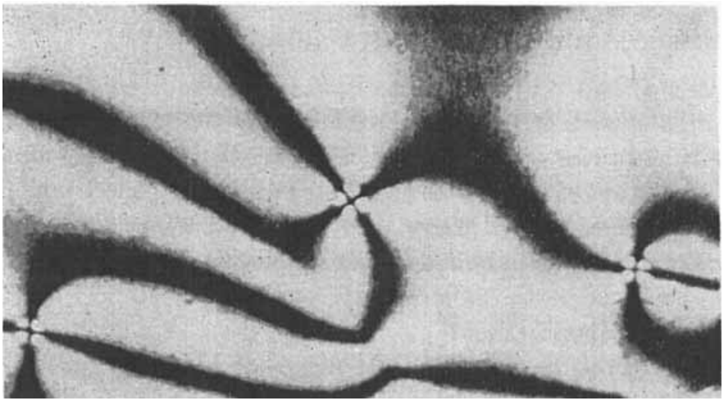


Figure 4. An enlarged photograph of the P structures typically shown in Fig. 7(f), 350 ×, white transmitted light, crossed polarizers.

nematic axis is vertical (parallel to the line of sight) at the center of the P structure. These observations suggest that it is a point disclination[5] symmetrical about a vertical line passing through the center of the point disclination schematically shown in Fig. 5. When the applied electric field was increased, the P structure became elongated such as those shown in Figs. 2(a), 2(b), 3(a), and 3(b). When the applied electric field was increased further, the P structure became more mobile and were often seen to generate pair of line disclinations at a time speeding toward opposite sides of the electrode and vanishing at the electrode–liquid crystal interface.

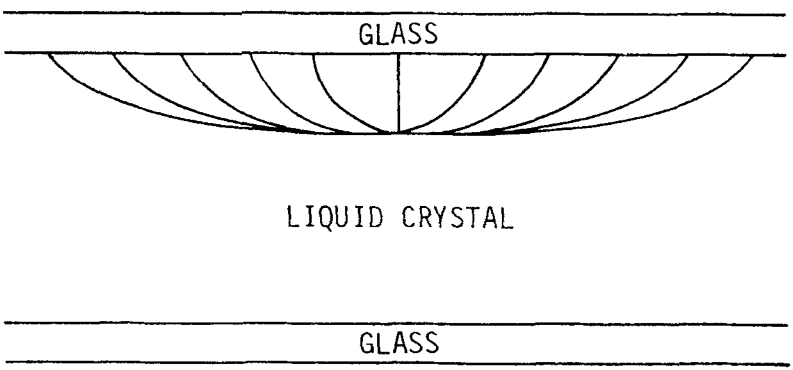


Figure 5. A schematic internal structure of a point disclination in a liquid crystal film having a zero-field H structure.

Homeotropically Aligned Film Under Zero Field

Figures 6(a) and 6(b) are microstructures under transmitted white light of a doped MBBA film (conductivity 3.5×10^{-10} mho-cm^{-1}) under 20 volts rms at 60 Hz. The film had the V structure under no field. Small ac field nucleates the H structure at the electrode–liquid crystal interface which grows into the V structure with a wavy boundary. The B-type boundary is very mobile and can be reversibly moved back and forth upon slightly changing the ac field below the Williams domain threshold.

Figures 7(a) to 7(f) illustrate a sequence of microstructures viewed with transmitted white light under crossed polarizers of a doped MBBA film having a stable V structure under zero field. Figure 7(a) appears uniformly dark under zero field. Figures 7(b) and 7(e) were

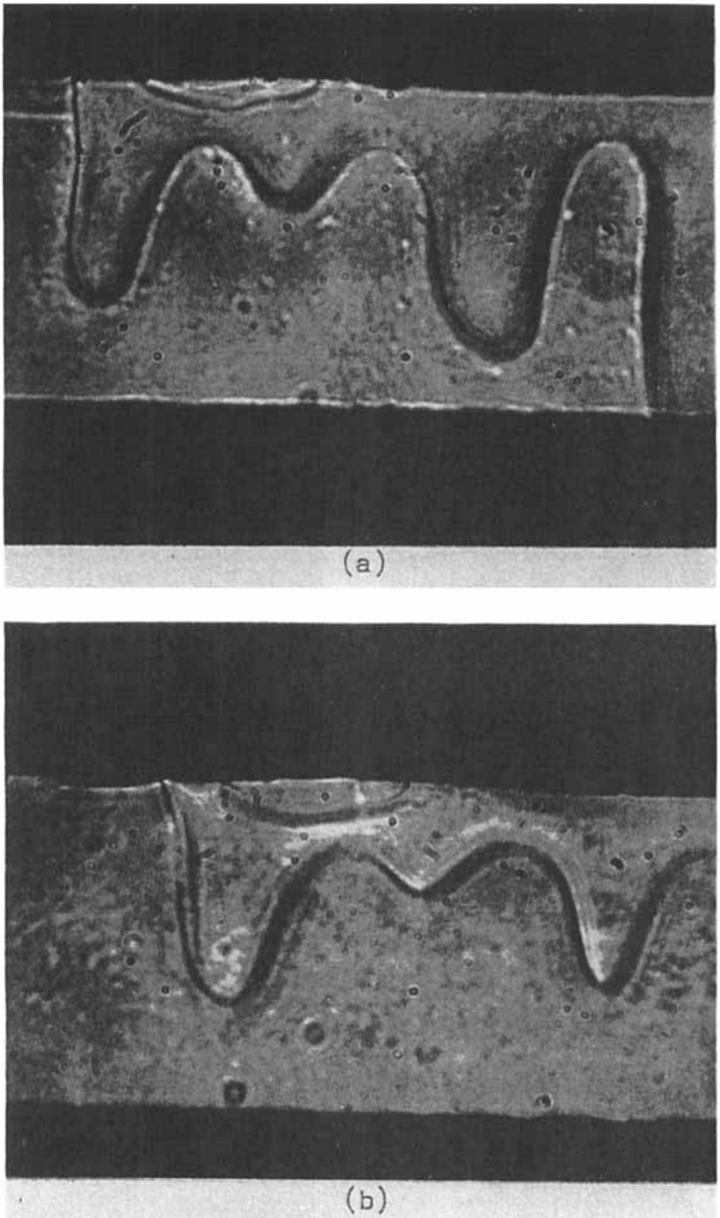


Figure 6. Transverse structure of doped MBBA film (conductivity 3.5×10^{-10} mho-cm^{-1}) under ac field below the Williams domain threshold, showing field induced conversion of the V structure into the H structure, 370 ×, transmitted white light (Fig. 6(a), 20 V rms; Fig. 6(b), 20 V rms; $l/d \sim 2.5$).

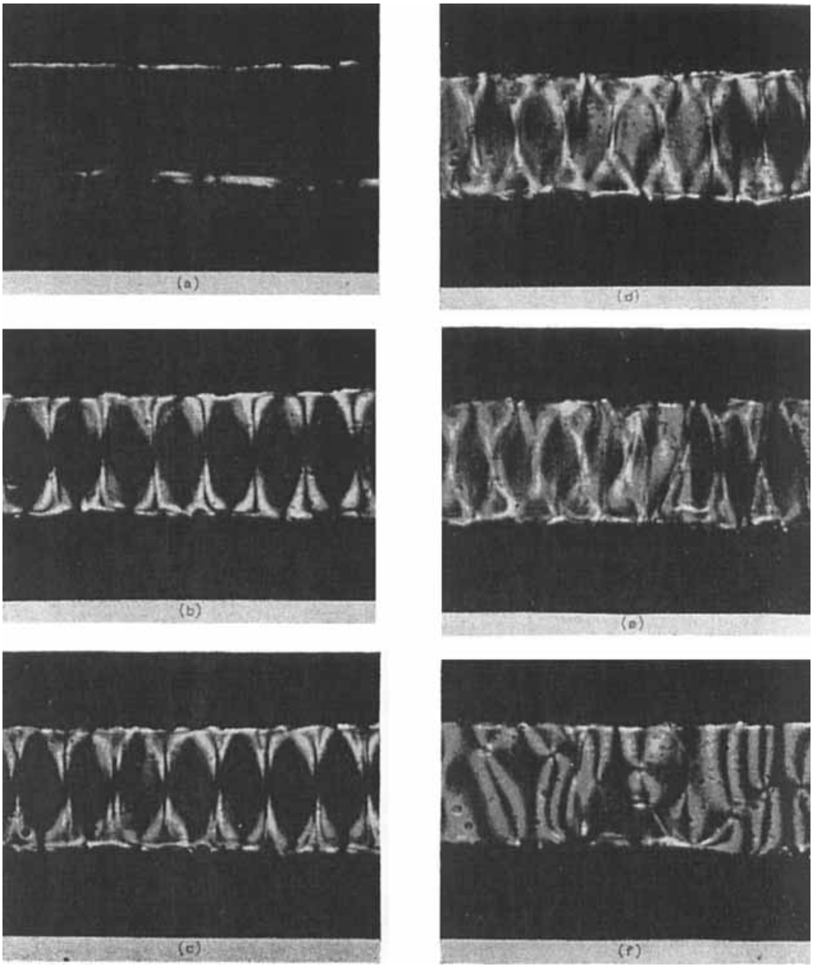


Figure 7. Transverse structure of doped MBBA film (conductivity 3.5×10^{-10} mho-cm^{-1}) under 60 Hz ac field, 185 ×, crossed polarizers (Fig. 7(a), zero field; Fig. 7(b), 31 V rms; Fig. 7(c), 35 V rms; Fig. 7(d), 39 V rms; Fig. 7(e), 43 V rms; Fig. 7(f), taken immediately after turning off field from 100 V rms; $l/d \sim 3$).

taken at, respectively, 31, 35, 39, 43 V rms at 60 Hz. At 31 V, the liquid crystal directors tend to rotate toward the applied electric field direction, forming banded and segmented V′ structures, a colored reproduction of which is shown in Figure 8. At 39 V the

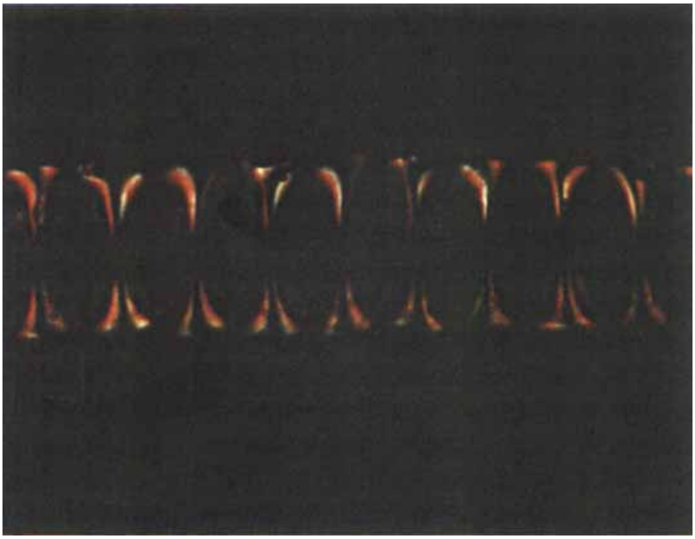
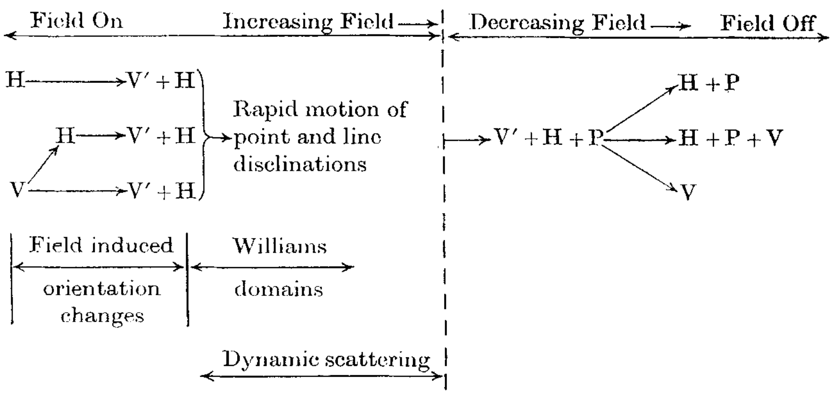


Figure 8. A colored reproduction of the microstructure corresponding to the state represented by Fig. 7(b).

center of each band becomes a P structure and begins to emit pair of line disclinations (at a time) speeding towards the opposite electrodes and disappearing there. This is presumably a microstructural version of the beginning of the " dynamic scattering " state. Figure 7(f) was taken immediately after the cell was excited to 100 V rms (60 Hz) for 10 sec and the field was turned off, showing a H structure containing a number of P structures. After a brief rest at zero field (~60 sec), the microstructure returned to the state shown in Fig. 7(a), i.e., the H structure was converted back to the V structure.

A careful analysis of the above observations suggest the following paths taken by a doped MBBA film under low-frequency ac excitation:



At present we do not know what prevented the conversion of the V to the H structure for the case shown in Figs. 7(b) to 7(e) in contrast to those shown in Figs. 6(a) and 6(b). It is likely that in the latter there were present nuclei of the H structure or imperfections which form readily the H structure nuclei at the glass–liquid crystal interface under field, while in the former the H structure was not formed at all presumably such imperfections were not present. Upon turning off the electric field from the " dynamic scattering " state, H structure containing many point disclinations always formed first; the final V structure may or may not form depending on surface conditions at the glass–liquid crystal interface. Thus, the microstructural changes of doped MBBA films in response to applied low-frequency ac electric fields vary with the nature of surface preparation of the glass plates. It is to be noted here that the surface conditions of clean glass plates can be altered readily by means of surfactants either deposited onto the glass substrate or added to the liquid crystal.

Our experimental observations suggest that the onset of the " dynamic scattering " state, from a microstructural point of view, takes places principally by the motion of point and line disclinations. Another type of motion, although less frequently observed, is the rapid motion of line disclinations (the B boundaries) shown in Figs. 6(a) and 6(b), where the line disclination separating the V and the H structure moves rapidly and disappears at the electrode–liquid crystal interface. The interaction of point and line disclinations in liquid crystals with different force fields, whether it be mechanical, thermal, electric or magnetic in origin, appears to be fascinating and fruitful subjects for future investigations.

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