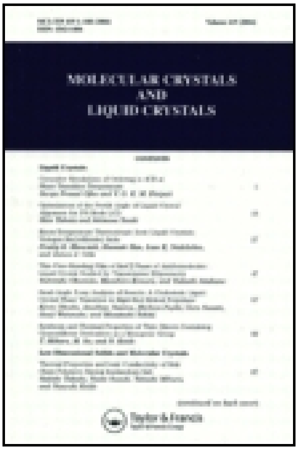

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Banded Texture of Lyotropic Polymer Liquid Crystal

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The formation of the banded textures evolved in the liquid crystalline solution of poly(γ-benzyl L-glutamate), PBLG, when an alternating electric field applied parallel to glass surfaces (in-plane), was investigated. The director rotation in the band appeared as regular stripes perpendicular to the field direction was analyzed by using polarizing microscope and measuring the light intensity under crossed polarizers. The detailed map of directors in the area of band was performed.

Keywords: banded texture; in-plane electric field; polypeptide

INTRODUCTION

It is more than twenty years since the transverse striations were observed to develop over a period of time after cessation of shear for liquid crystalline solution of poly(γ-benzyl L-glutamate), PBLG, in m-cresol1). Since then, the evolution of the banded texture that developed in lyotropic polymer liquid crystals during and after shear flow has been investigated for various this class of materials2). It is thus a common feature for the polymer liquid crystal (PLC). However, the mechanism leading to the formation of banded texture is still unknown in detail. Some understanding of these phenomena seems necessary for what concerns molecular orientations. The texture is transient and the band width increases as time progresses after cessation of shear, that is, the band developed after cessation of flow usually broadens and then disappears. The phenomenon is strongly time-dependent and also depends on the material under consideration and the experimental condition. Accordingly, the data provides only the qualitative insight into the rheological response of liquid crystalline polymers. Many people have suggested possible qualitative approach to this problem but detailed explanations are still lacking.

The phenomenon was found not only with a shearing field but the other external fields. When the solution of PBLG was allowed to stand in a magnetic field, it was found that a structure consisting of lines perpendicular to the magnetic field evolved3) and a similar effect was reported upon reversal of an electrostatic field4).

PBLG molecule has a permanent dipole along molecular axis and then the role of dipole-dipole interactions in determining this sort of properties of liquid crystalline solution of PBLG could hardly be neglected.

Previously, we found that the banded texture emerged under an alternating electric field applied parallel to the glass plates with which PBLG solution was sandwiched[5)-7)]. The observation was carried out on PBLG liquid crystalline solution in 1,1,2-trichloroethane and at the frequencies of electric field below about 0.02Hz. Under such a low frequency region, a particular texture developed in the solution, consisting of fine equidistant black lines as viewed between crossed polarizers. On insertion of a first-order plate at 45° to crossed polarizers, areas between the black lines became alternately blue and yellow. When a square wave was applied on, it was found 4 times of the band evolution in a cycle. Accordingly, it is considered the director in the solution rotated though ±180° , followed on an inversion of the field direction. We obtained quantitatively the relation between field strength and domain size for the texture induced by an electric field instead of a shear field and gave an interpretation on the evolution of banded texture as the results of the rotational motion of directors in a domain. It was clarified that the directors in a domain perfectly inverted the direction when the enough long pulse was applied. However, there are some difficulties, which must be exceeded in order to consider the model of perfect reorientation.

In this work, we tried to analyze the rotational mode of the director, which appeared when limited frequency was applied. The main objective of this work was to investigate the reorientation mechanism in this system and to represent the model of director rotation.

EXPERIMENT

PBLG used in this experiment was prepared by polymerization of NCA and the molecular weight was estimated as 70,000. The concentration of the solution of PBLG in 1,1,2-trichloroethane amounted to 0.18 by volume. The solution, after incubation at room temperature at least for 24h, was sandwiched between two parallel glass plates coated partially with Au as electrodes, as shown in figure 1. The level dimensions of the cell were 0.5cm*0.5cm and the cell thickness were 80μm. A schematic experimental set up is shown in figure 1. The cell was mounted on a polarizing microscopic between polarizers. The lower polarizer is placed parallel to the electric field direction and the upper is perpendicular to it. The real images were recorded using CCD camera. The square wave form of ac electric field, the field strength up to $720V_{p\text{-}p}$/cm and the frequencies up to 1Hz was used. After the individual frames of recorded images were digitized, a certain horizontal line parallel to the electric field was picked up at a regular interval (0.25sec.:4 lines in a second) and the digitized optical pattern was reconstructed on the time scale.

RESULTS AND DISCUSSION

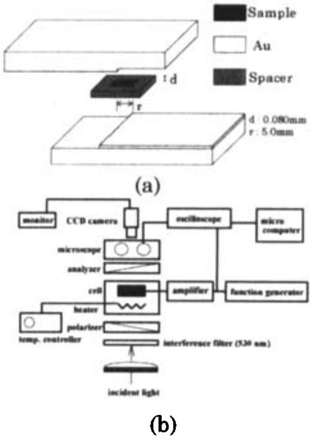

FIGURE.1 The experimental set up.

A homeotropically uniform alignment of main chain of PBLG is obtained without an external field is applied if the cell thickness is somewhat thin. However, a unique reorientation behavior has been observed in this polymer when an alternating (AC) electric field, lower than 0.01Hz, is applied perpendicular to the original director, where appears a periodic array of stripe domains perpendicular to the field. These stripes have a fairly regular width of several microns and the rotation of the director in the areas between black lines occurs in opposite direction towards the axis of external field from one stripe to another in an alternating fashion. The bands appear 4 times in a cycle of AC electric field and their evolution repeatedly again and again. The banded texture, which once appeared, remains as it is. As an example of the banded texture, a photograph under crossed polarizer is shown in figure 2, where the relative maximum intensity is white and the relative minimum is black.

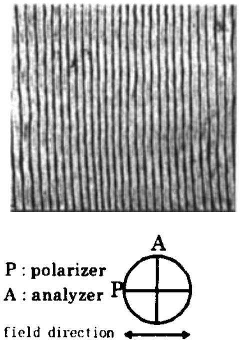

FIGURE 2. The banded texture

The optical intensity of light transmitted through the whole area of the sample was measured. Four different characteristic optical responses in a cycle of the applied AC field are observed, depending on frequency. The typical three response forms are shown in figure 3a, as the variation of optical intensity through the whole area of a sample, with the waveforms of electric fields. Furthermore the optical response depends on the voltage of the applied electric field. As shown in figure 3b, there exist six regimes, that is, the different patterns appeared as a function of the frequency and the voltage of the applied electric field. One of them is the regime where a quiescent state appears and others where dynamic motions containing a dynamic fluctuation are observed. It was found that in two regions, A and C, the response form continues, as it is, semi permanently, while in the other regions, B and D, the type of the response varies with the passing of time and through a chaotic situation, leads to rest finally.

In the lowest frequency region, A, the directors seem to be inverted perfectly with ± 180° rotation of them on a reversion of the field direction. It is difficult to estimate consistently the director movement in this region. Although these bands appear to be similar to the Williams domain in low molecular weight liquid crystals, their interpretation could not satisfy our optical observation. An entire explanation of the inversion process of director in the band emerged in the system under consideration may not satisfy the criteria of optical observations. Here, we concentrated our attention upon the problem to clarify the mechanism of director rotation in another stationary regime, C.

As an example, the digitized optical light patterns evolved under the AC field of 720 $V_{p\text{-}p}$/cm at a frequency of 0.2Hz, are shown in figure 4, where the real observation was made between crossed polarizers. The relative maximum intensity is white and the relative minimum is black. A fixed horizontal line of the banded texture was picked up at a regular interval (4 lines in a second) and the pattern was reconstructed on the time scale, as shown in the lower figure, where the vertical axis represents time in second and the horizontal axis is a line across the stripes, parallel to the field direction, at an instant.

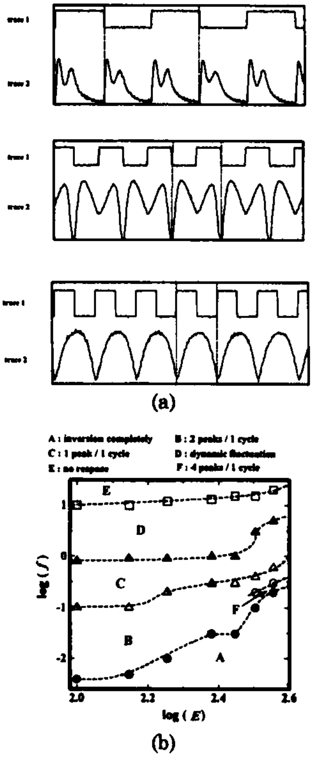

FIGURE 3. (a) The variation of optical, transmittance with wave form of AC field (trace 1). (b) The dependence of the response on frequency and field strength.

The optical intensity of local position in a band was analyzed. As an example, on the digitized image of texture in figure 4, the variations of optical intensity along vertical lines and horizontal lines are shown in figures 5 and 6, respectively. In figure 5a, time dependences of optical intensity along the lines indicated by arrows in 5b are shown, where the line number indicated in figure 5a, increases in order from left to right. It is found that at band boundary, the intensity changes slightly and the directors remain nearly parallel to the horizontal axis. There is hardly any doubt about it. Because the boundaries appears as black lines under crossed polarizers where one polarizer is oriented at 0° with respect to the field direction and the other is perpendicular to the field, whereas they appeared to be bright when both polarizers are parallel to the field.

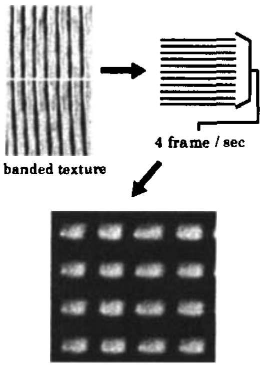

FIGURE.4 The digitized optical pattern.

It seems that the cell gap of 80μm is enough to confine the rotational motion of director nearly in a plane parallel to the field direction for this system under consideration. The variations of angle, θ, between the director and the field direction were estimated from the optical intensity in figure 6b.

As shown in Fig.6 that in the center part of a domain, the molecules of a limited range joint together and begin with rolling motion, soon after the inversion of field direction. Widths of the range showing the same amount of deformation tend to decrease with increasing of the rotational angle θ of director in the duration of a square wave. The angle decreases gradually from the center to domain boundary along x axis parallel to the field direction and leads to the minimum value at the boundary.

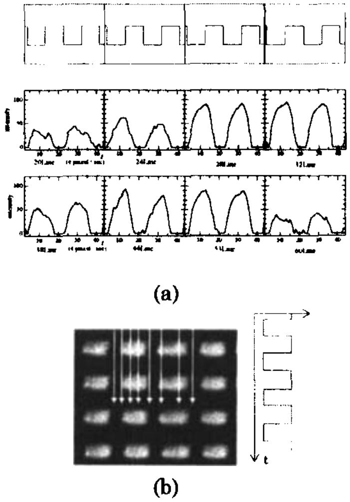

FIGURE 5 The time dependence of optical transmittance at the local positions, shown as arrows in (b).

In the center of a domain, the angel θ amounted to about ±45° We tried to make the detailed map of the director orientation at local position in a domain and domain boundary. As shown in figure 7, the serpentine motion of directors sustains in a plane parallel to the glass plates.

CONCLUSION

When the low frequency of an AC electric field with square waveform was applied on the PBLG concentrated solution, parallelly to the cell surface, the characteristic banded texture appeared 1 to 4 times in a cycle, depended on the frequency. In the regime with which the band appeared once in a cycle, the response followed by an inversion of the field direction continued semi-permanently. It was found that the texture formation associated with periodic twist deformation and the directors in the center of area between boundaries rotated ±45° to the field direction at most, while in the band boundary they remained within a small angle to the field.

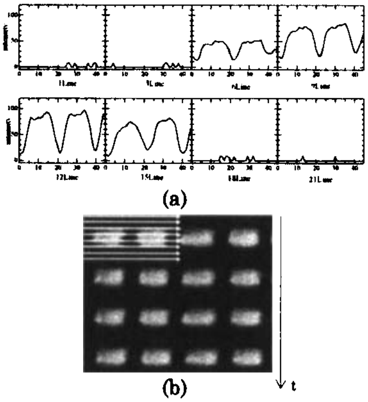

FIGURE 6 The time dependence of transmittance along a line across two bands.

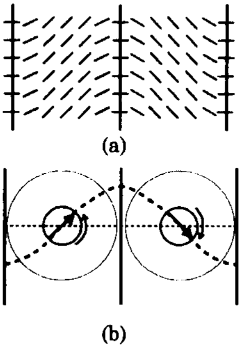

FIGURE 7 The schematic model for the twisted rotation of the directors. The vertical lines are shown as the domain boundary. The two arrows in the center of domain represent the director.

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