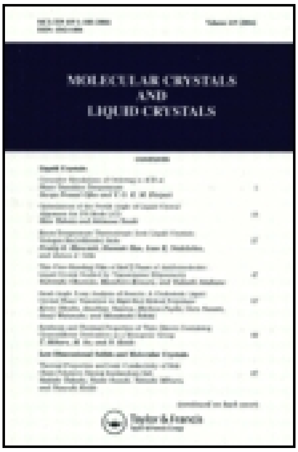

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Thermo-Optic Effect of Smectic A Liquid Crystals in Hybrid Cells

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Thermo-Optic Effect of Smectic A Liquid Crystals in Hybrid Cells

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For cells having a hybrid boundary condition, the thermo-optic effect has been investigated during the cooling process from a nematic to a smectic A phase under the influence of an electric field. The texture and the transmission that occurs during the smectic A phase strongly depend on the bias voltage. To investigate the layer alignment in smectics, the capacitance of the cell is measured for various textures, and the relationship among textures, transmission, and capacitance is discussed. Also investigated is the phenomenon of textural relaxation near the smectic A to nematic phase transition temperature. It was found that the field-induced homeotropic texture relaxes to the preferred scattering texture through the nucleation of spherulites.

Keywords: smectic A liquid crystal, thermo-optic effect, textural change, textural relaxation, capacitance analysis

1. INTRODUCTION

The molecular alignment of liquid crystals can be easily altered by the application of an electric field or by the variation of temperature. In the smectic A phase, the change in the molecular alignment results in a change in the light scattering characteristics. Since the first demonstration of thermally addressed liquid crystal displays by Kahn,[1] the thermo-optic effect of the smectic A liquid crystal has been investigated by many researchers. These investigations were prompted by the interest in either the fundamental aspects[2–5] or applicative purposes[6–9] of liquid crystals.

Recently, Chu et al.[6] studied the thermo-optic effect under a competing boundary condition, in which the light-scattering characteristics in the smectic A phase were investigated. However, the textural change in the liquid crystal relating to the change in the optical transmission has not been investigated in detail. It is important to study the mechanism of the thermo-optic effect, not only for a fundamental understanding of liquid crystals, but also for applications as a display device.

In this paper, the thermo-optic effect is investigated under the influence of an electric field. In particular, an examination is made of the relationship between the optical transmission and texture of the smectics. Furthermore, the textural relaxation which occurs during the smectic A phase is also discussed.

2. EXPERIMENTAL PROCEDURE

The smectic A liquid crystal used in the present experiments was 4'-*n*-octyl-4-cyanobiphenyl (8CB, Merck), which had a positive dielectric anisotropy. The phase transition temperatures of this compound are as follows: K-21.5°C-S_A-33.5°C-N-40.5°C-I. The samples were sandwiched between two transparent electrodes having spacers of various thicknesses (6–100 μm). One of the electrodes was treated by oblique deposition of SiO to obtain homogeneous boundary conditions, while the other was coated by lecithin to produce homeotropic boundary conditions (hybrid cell).

The cell was mounted in a microfurnace (Mettler, FP-52). It was then slowly cooled (1°C/min) from the nematic phase to a smectic A phase under the influence of an electric field (1 kHz). The textural change that occurred during the nematic to smectic A phase transition was observed by a polarizing microscope (Nikon Apophoto). The thermo-optic properties were studied with the help of a photomultiplier fitted to the eyepiece of the microscope and also by measuring the capacitance of the cells with a LCR meter (YHP, 4261-A).

3. RESULTS AND DISCUSSION

3.1 Thermo-Optic Effect of Smectic A Liquid Crystals

The transmission change that occurred during the cooling process from the nematic to smectic A phase is shown in Figure 1. From this figure, it is clear that the transmission in the smectic A phase strongly depends on the bias voltage applied during the cooling process.

When no bias voltages were applied, the transmission abruptly decreased at the nematic to smectic A phase transition temperature (T_{AN}). In this case, the scattering texture of the honeycomb shape was formed from a striped texture[2] in the smectic A phase, as presented in Figures 2a and 2b. Contrary to cells having a parallel boundary condition,[5] in the hybrid cells the scattering textures are formed without the aid of an electric field.

In the range of lower bias voltages ($0 < V_B < 10$ V), the transmission in the smectic A phase exhibited a lower value, independent of the bias voltage. When the bias voltage was removed at a temperature 3°C below T_{AN}, no change was observed in the transmission. Although the honeycomb scattering texture was formed in this range, the microscopic observation revealed that the domain size decreased as the bias voltage increased.

On the other hand, when the bias voltage increased above 10 V, the transmission at a temperature 3°C below T_{AN} increased with increasing bias voltages. Under the bias voltage of 15 V, the scattering texture presented in Figure 2c was directly formed without the formation of stripes. The detailed observation revealed that

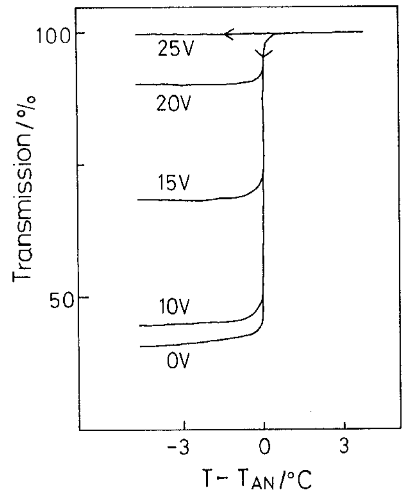

FIGURE 1 Thermo-optic effects of smectic A liquid crystals in a hybrid cell. The sample is 8CB with a thickness of 25 μm. T_{AN} = 33.5°C.

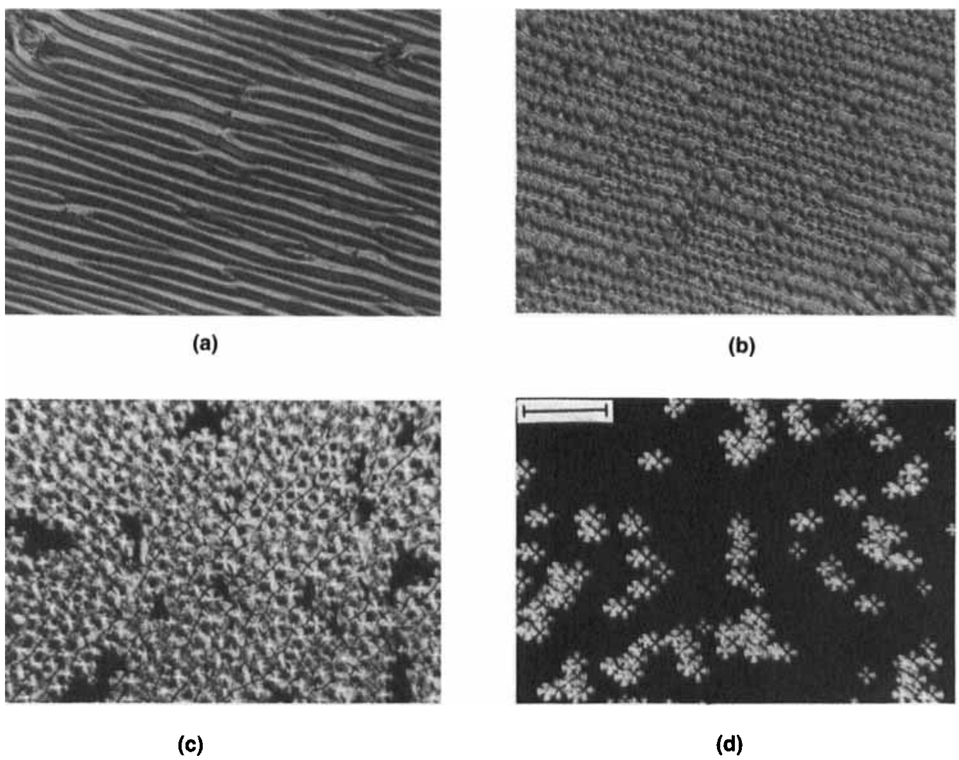

FIGURE 2 Microphotographs of textures formed during the smectic A phase under the various bias voltages: (a) striped texture observed at T_{AN} (0 V), (b) honeycomb texture (0 V), (c) densely packed spherulites (15 V), and (d) spherulites embedded in the homeotropic matrix (20 V). The bar represents a length of 100 μm. The cell thickness is 25 μm.

the scattering texture thus formed consisted of densely packed spherulites. These domains are considered to be focal conics in which the ellipses degenerated into circles.[3] It should be noted that the homeotropic matrix can also be observed in Figure 2c.

When the bias voltage was further increased to 20 V, the spherulites decreased, as observed in Figure 2d. At a bias voltage of 25 V, the transmission showed no change, even during the smectic A phase. In this case, the homeotropic texture was formed over the entire area of the cell. The transmission of the cell increased as the homeotropic matrix increased.

Two types of smectic scattering textures, honeycombs and spherulites, were formed in the thermo-optic effect. One texture or the other will appear as a result of the competition between the force generated by the surface and that induced by the electric field.

3.2 Capacitance Analysis

It is well known that the capacitance of the cell is correlated to the molecular alignment of liquid crystals. Therefore, in order to investigate the layer structure, the capacitance of the cell was measured at a temperature 3°C below T_{AN} for each cooling process after the removal of the bias voltage. The results are shown in Figure 3, where the solid circles show the capacitance as a function of the bias voltage. The dependence of the transmission on the bias voltage is also shown in Figure 3.

When the cell was cooled to the smectic A phase without the application of a bias voltage, the capacitance showed the minimum value. In this case, the competing boundary conditions cause the layer structure with a splay deformation in the form of the honeycomb texture.

In the lower bias voltage range ($0 < V_B < 10$ V), the capacitance of the cell

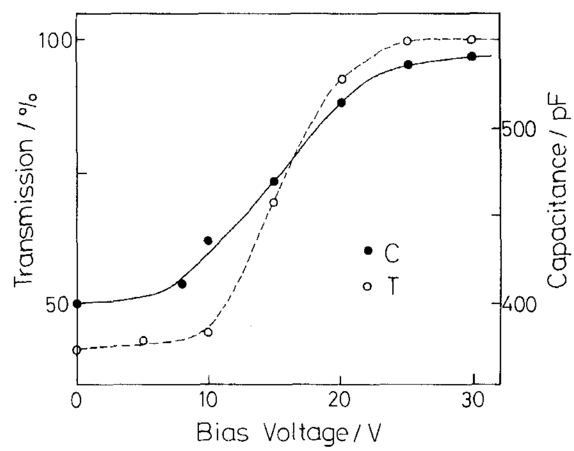

FIGURE 3 The capacitance and transmission as a function of the bias voltage, indicated by solid and open circles, respectively, in the smectic A phase at a temperature 3°C below T_{AN}. The cell thickness is 25 μm.

remains almost constant. This suggests that the layer structure also remains unchanged over this range.

For the higher bias voltage range (10 V < V_B < 20 V), the capacitance of the cell increased as the bias voltage increased. In this range, the molecules in the nematic phase are aligned almost parallel to the electric field, except for those in the surface region under the influence of a homogeneous boundary condition. When the cell is cooled to the smectic A phase, the competition between the layer structure at the surface and that in the bulk produces the spherulites. The capacitance increases as the density of the spherulites decreases.

When the bias voltage was further increased above a value of 20 V, the capacitance showed a tendency to saturate. In this range, the homeotropic matrix filled the cell. From the above descriptions, it is found that the honeycomb texture appears when the surface effect prevails over the field effect, while the spherulites appear when the field effect becomes dominant over the surface effect.

3.3 Textural Relaxation

Generally, in a smectic A liquid crystal, the field-induced texture persists, irrespective of the boundary condition. In fact, at a temperature 3°C below T_{AN}, no change was observed in either the transmission or the texture after the removal of the bias voltage. However, in the vicinity of T_{AN}, the thermal properties of smectic A liquid crystals have not been studied. In this section, the thermo-optic effect was investigated during the heating process from the smectic A to nematic phase.

The initial state of the smectic phase was a homeotropic texture, induced during the cooling process under a bias voltage of 25 V. When this initial texture was slowly heated (0.2°C/min), the transmission decreased near T_{AN} prior to the phase

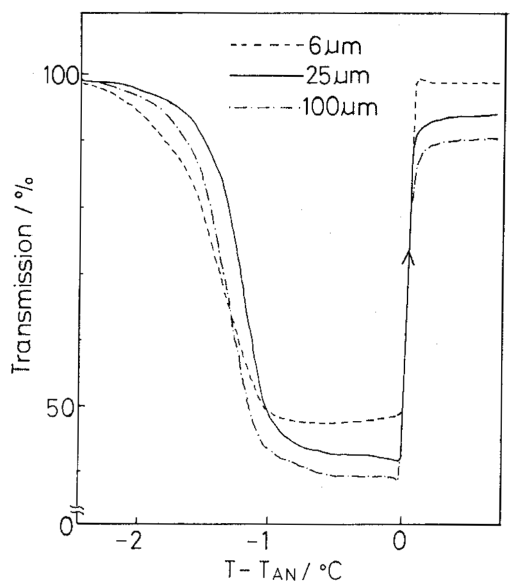

FIGURE 4 The transmission change during the relaxation process from a field-induced homeotropic texture to the preferred scattering texture for three different thicknesses.

transition, as seen in Figure 4. This means that the field-induced homeotropic texture becomes unstable near T_{AN}.

The textural change was observed as follows. At a temperature 1.5°C below T_{AN}, a few isolated spherulites nucleated in the homeotropic matrix (Figure 5a). This brought about a slight decrease in the transmission. With increasing temperature, the spherulites increased in number (Figure 5b), which in turn caused the gradual decrease in the transmission.

When the temperature reached a value of 0.5°C below T_{AN}, the cell was filled with densely packed spherulites (Figure 5c). With a further increase in the temperature, these spherulites interacted among themselves to form the scattering texture. This resulted in a lower value in the transmission, the same as that during the cooling process with no electric fields. Finally, the transmission intensely increased in the nematic phase.

The observations in Figure 5 reveal that, in the vicinity of T_{AN}, the layer structure aligned parallel to the surface relaxes to the preferred alignment with a splay deformation through the nucleation of spherulites (Figure 5d). It appears that the temperature at which the relaxation takes place does not depend on the cell thickness (Figure 4). However, the relaxation develops as the temperature is increased. The details of the textural relaxation in a smectic A liquid crystal will be reported elsewhere.[10]

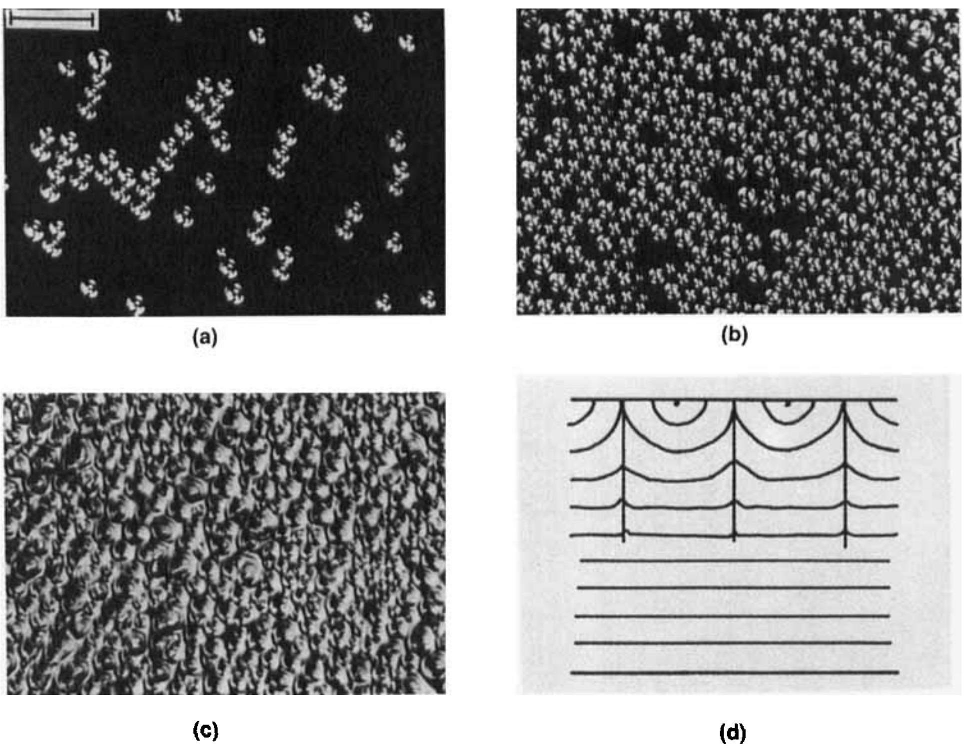

FIGURE 5 Microphotographs of textures formed during the relaxation process: (a) T-T_{AN} = -1.5°C, (b) T-T_{AN} = -1.0°C, and (c) T-T_{AN} = -0.5°C. A schematic model of the layer alignment in spherulites (d). The bar represents a length of 100 μm. The cell thickness is 25 μm.

4. CONCLUSIONS

For cells having a hybrid boundary condition, two types of scattering texture were observed in the thermo-optic effect under the influence of an electric field. From the capacitance analysis, it was found that the honeycomb texture appeared when the surface effect was dominant over the field effect, while spherulites appeared when the field effect was dominant. Near the smectic A to nematic phase transition temperature, the field-induced homeotropic texture relaxes to the preferred texture through the nucleation of spherulites.

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