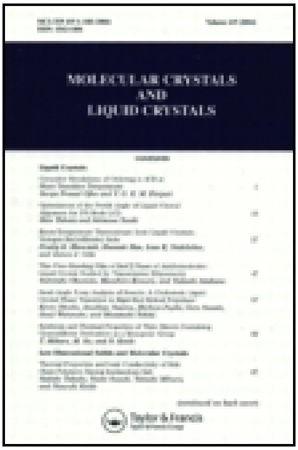

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Light Transmission and Texture Changes of Mixed Liquid Crystals by Temperature Variations

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Light Transmission and Texture Changes of Mixed Liquid Crystals by Temperature Variations

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The changes in liquid-crystal light transmission caused by temperature variations are investigated in connection with texture changes. Materials under investigation are the nematic-cholesteric and the smectic-cholesteric mixed liquid crystals. In the nematic-cholesteric mixed liquid crystal, the light scattering centers produced by the temperature variation from the liquid phase to the cholesteric phase cannot disappear with the applied voltage of 1 kHz. On the contrary, the light scattering centers produced in the dynamic scattering mode can disappear with the applied voltage of 1 kHz. In the cholesteric phase of a smectic-cholesteric mixed liquid crystal, the planar texture appears in a heating process but the focal conic texture in a cooling process. This texture difference causes the difference in the light transmission between the heating and the cooling processes. Further, the difference in the light transmission of a planar texture depends on the mesh area: as the area is larger, the transmission is greater.

1 INTRODUCTION

The change in light transmission (or light reflection) caused by applied voltage or temperature variations has been studied mainly in various optical effects of liquid crystals. Microscopically, the light-transmission change of liquid crystal is due to the texture change of liquid crystal. Textures of liquid crystals have been extensively investigated relating to ordering of molecules.[1–3] Table I shows the typical textures of liquid crystals. Texture changes in the cholesteric phase of nematic-cholesteric mixed liquid crystal reported so far were caused mainly by applied voltage[4–10] and only in some cases by temperature variations.[11,12]

In this paper, we describe (i) light transmission and texture changes by applied voltage from opaque to transparent state of nematic-cholesteric

TABLE I

Main textures appearing in nematic, nematic-cholesteric (mixture), and smectic liquid crystals

	Liquid crystal	Texture
Liquid crystal and texture	Nematic →	Homogeneous Homeotropic Williams domain Chevron
	Cholesteric (Nematic cholesteric mixture) →	Planar Focal conic Bubble
	Smectic →	Fan-shaped Polygonal Mosaic

mixed liquid crystal where the opaque state has been caused by temperature variation, and (ii) those changes by temperature variations in a smectic-cholesteric mixed liquid crystal. The former is important for electrically erasing function and the latter for wrtie-in speed to be increased, because multifunction for display and increase of address speed are required for improvement of display characteristics of thermally addressed liquid-crystal light valve.[13]

2 NEMATIC-CHOLESTERIC MIXED LIQUID CRYSTAL

The mixed liquid crystals of this type have in general the following transmission characteristics:

i) when a transparent liquid crystal is heated to the liquid phase and then cooled down to the original temperature, it changes to an opaque state, as shown in Figure 1,

ii) when a voltage of 1 kHz is applied on an opaque liquid crystal, the transparency is increased but not recovered to the original transparency, as shown by the solid line in Figure 2, and

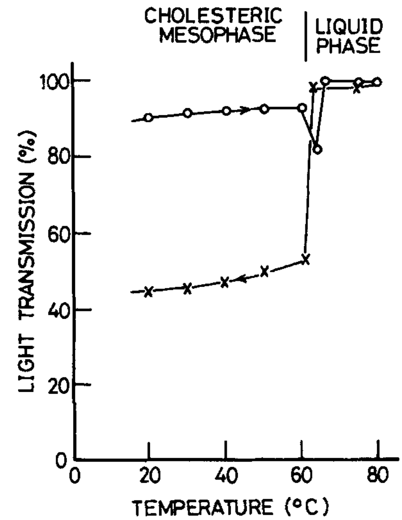

FIGURE 1 Typical temperature dependence of light transmission of nematic-cholesteric mixed liquid crystal.

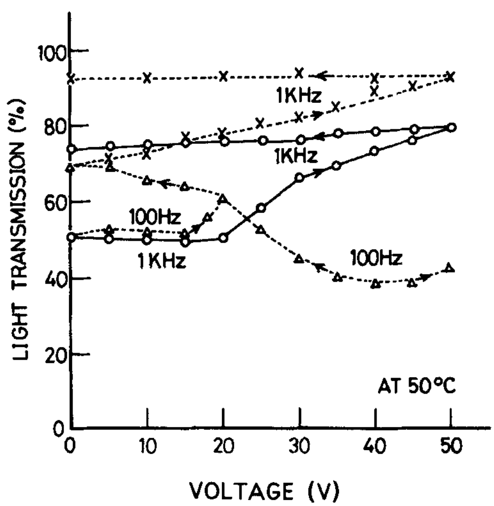

FIGURE 2 Typical voltage dependence of light transmission of nematic-cholesteric mixed liquid crystal.

iii) after the dynamic scattering is induced by the voltage of 100 Hz, the applied voltage of 1 kHz makes recovery to the original transparency, as shown by the broken line in Figure 2.

These phenomena are understood as follows. The light scattering centers produced in the temperature variation from the liquid phase to the cholesteric phase cannot disappear with the applied voltage of 1 kHz. They would be converted to new light-scattering centers with the applied voltage of 100 Hz which causes the dynamic scattering mode. The light-scattering centers produced in the dynamic scattering mode can disappear with the applied voltage of 1 kHz.

Experiments were performed using the mixed liquid crystal of *MBBA*: *EBBA*:*CN* = 45:45:10 (in weight percent).† Here, the *MBBA* and the *EBBA* are nematic and the *CN* is cholesteric.

The microscopic observation of opaque state caused by the temperature variation from the liquid phase to the cholesteric phase is shown in Figure 3(a). The focal conic texture can be seen uniformly in the whole of a cell. The texture change by applied electric field of 1 kHz and 10 kv/cm to the cell is shown in Figures 3(b) and (c). The focal conic texture is not converted to a uniform planar texture, but the cell shows net-like lines which would be the interface at which the direction of molecular axis changes abruptly. Thus, they would correspond to the grain boundary of a polycrystal. As the electric field intensity is increased or the time goes on under a constant field intensity, a transparent area in the net becomes larger, and then the light transmission through a cell increases correspondingly. Even though the field intensity is further increased to 40 kv/cm, the net-like lines cannot disappear as shown in Figure 3(d) and (e). They prevent the cell from recovering to a transparent state.

The liquid-crystal cell is again in an opaque state as shown in Figure 3(a). The texture change due to the applied voltage of 100 Hz is shown in a series of photographs in Figure 4. Figures 4(a) and (b) are the textures under the applied voltage of 12 and 18 V, respectively. Those are the mixed texture of the focal conic and the planar. When the applied voltage is further increased, the dynamic scattering appears. When the voltage reaches to 40 V, the bubble texture appears as shown in Figure 4(c).

The electric field of 1 kHz is applied to the cell after the voltage of 100 Hz is switched off. The texture change due to the increase in the field intensity is shown in a series of photographs in Figure 5. The mesh area of a planar

† *MBBA*: *p*-methoxybenzylidene-*p*′-*n*-butylaniline; *EBBA*: *p*-ethoxybenzilidene-*p*′-*n* butylaniline; *CN*: cholesteryl nonanoate.

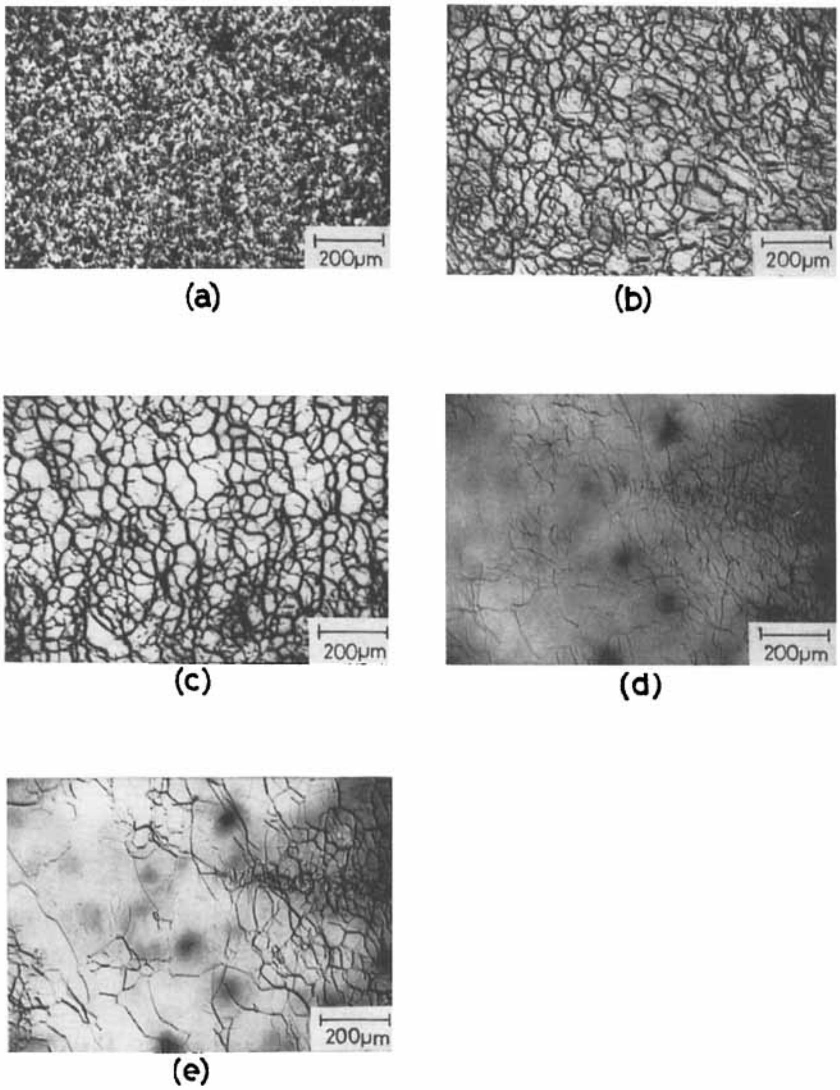

FIGURE 3 Texture change of nematic-cholesteric mixed liquid crystal. (a): focal conic texture (in cholesteric phase) resulted from liquid state. (b) ~ (e): texture change caused by applied field of 1 kHz.

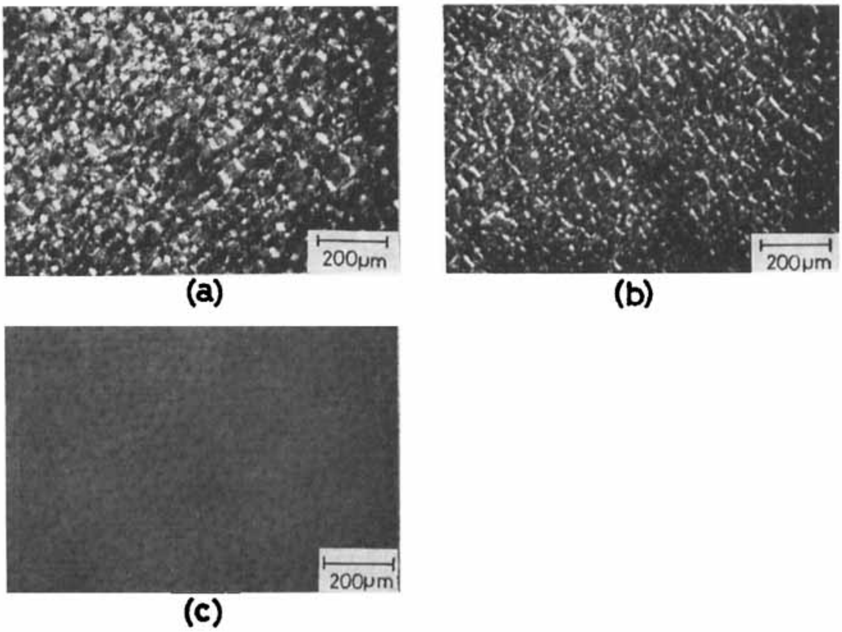

FIGURE 4 Texture change of nematic-cholesteric mixed liquid crystal. Change is caused by applied voltage of 100 Hz. (a) and (b): 12 and 18 V, mixture of focal conic and planar textures. (c): 40 V, bubble texture.

texture becomes larger with the field intensity. Finally, with the field of 40 kv/cm the net disappears completely as shown in photographs from (e) to (f), and thus the transparency is recovered. It is the contrast to the result of the applied voltage of 1 kHz as shown in Figure 3(e) where the net remains in a cell. The greater the applied voltage of 100 Hz is, the more easily the cell becomes transparent. Unless the voltage of 100 Hz is increased to the state where the net of the planar texture appears clearly in the focal conic texture, the transparency is not restored completely by the following applied field of 1 kHz.

The opaque state caused by the temperature variation from the liquid phase to the cholesteric phase is in the focal conic texture as shown in Figure 3(a). However, the opaque state caused by the dynamic scattering is in the texture involving the planar texture in the focal conic texture. The influence of this difference on recovering the transparency has not been interpreted.

The way of conversion, describing here, to the transparent from the opaque state which has been caused by the temperature variations can be used for electrically completely erasing function of a liquid-crystal light valve.

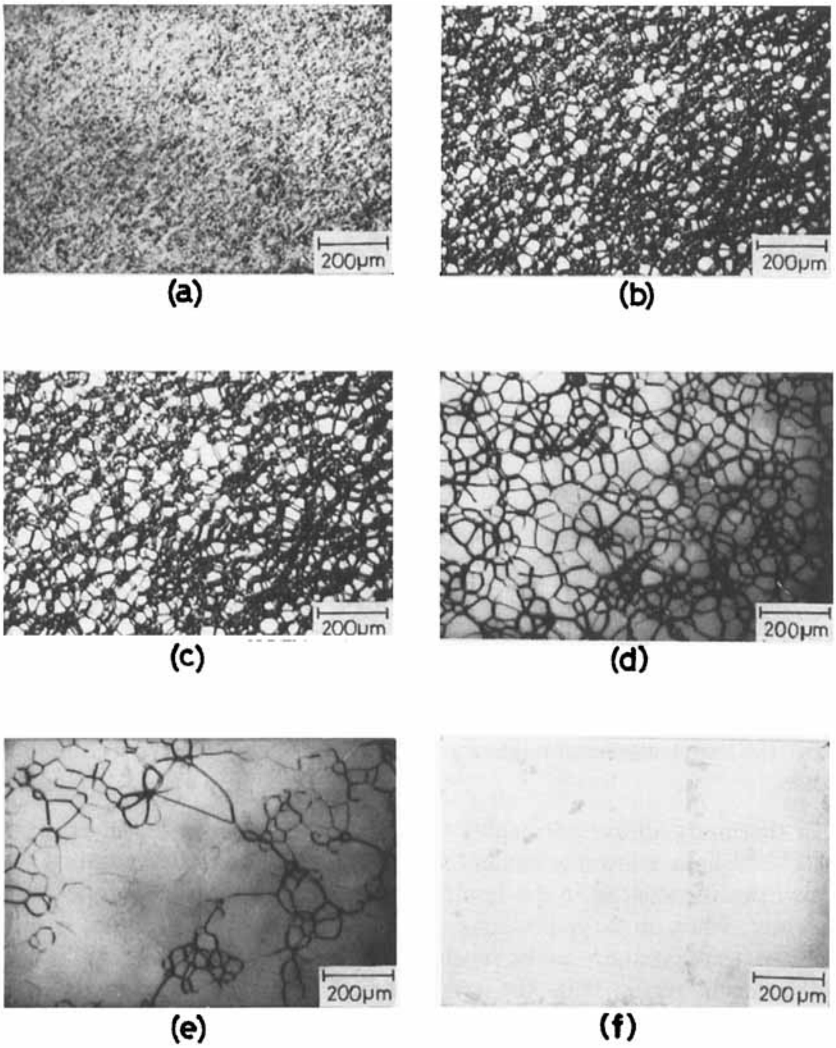

FIGURE 5 Change from mixture of focal conic and planar textures to transparent state through planar texture, (a) ~ (f). Change is caused by applied voltage of 1 kHz after application of 100 Hz.

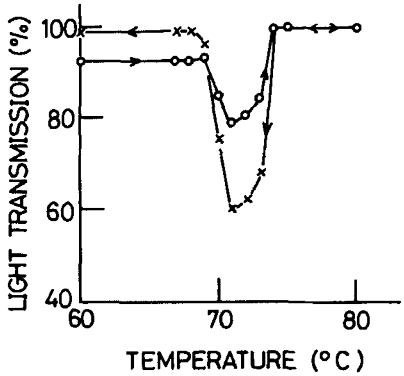

FIGURE 6 Typical temperature dependence of light transmission of smectric-cholesteric mixed liquid crystal.

3 SMECTIC-CHOLESTERIC MIXED LIQUID CRYSTAL

The mixed liquid crystals of this type have the following characteristics (Figure 6):

i) the light transmission is decreased in a cholesteric phase,

ii) the light transmission is lower in cooling than in heating process, and

iii) the light transmission is increased with the temperature in a cholesteric phase.

In thermally addressed display where a p-type smectic liquid crystal is used,[13–15] light scattering centers are produced by the temperature variations from the smectic to the liquid phase and frozen in the smectic phase. However, when an n-type smectic–cholesteric mixed liquid crystal is used, light scattering centers can be produced in the cholesteric phase and frozen in the smectic phase. Thus, the write-in speed can be improved by using the characteristics shown in Figure 6,† since temperature raise to the liquid phase is not required.

Experiments are performed using smectic–cholesteric, mixed liquid crystal of **HBBA:CN** = 90:10 (in weight percent).‡ The texture change observed in a heating process is shown in Figure 7(a)–(c). In a smectic A phase, the fan-shaped texture is observed as shown in Figure 7(a). At the transition temperature from the smectic A to the cholesteric phase, the

† The light scattering centers produced by the dynamic scattering in the cholesteric phase can also be used for the write-in operation.

‡ **HBBA**: *p*-hexoxybenzylidene-*p*′-*n*-butylaniline.

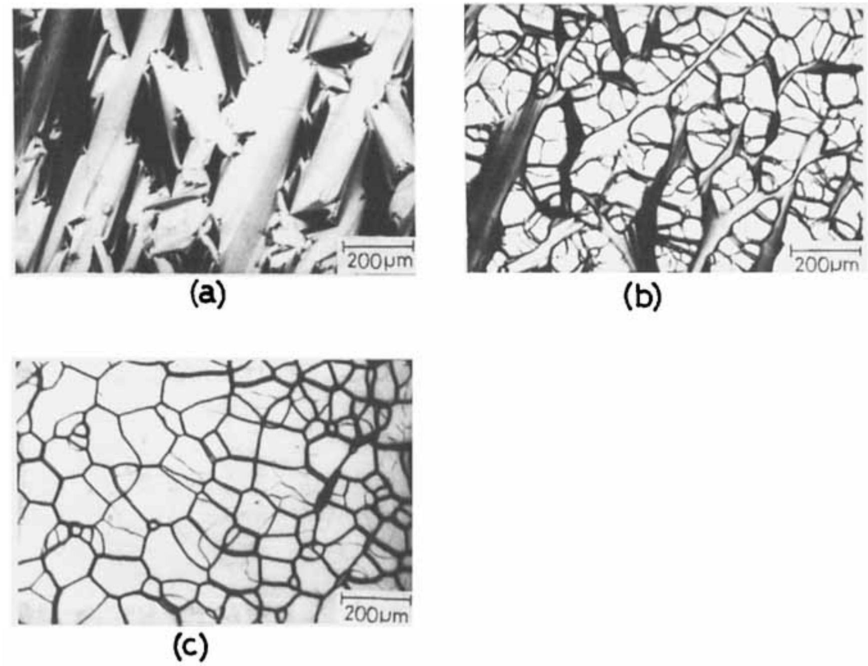

FIGURE 7 Texture change of smectic-cholesteric mixed liquid crystal from low to high temperature. (a): fan-shaped texture in smectic phase. (b): transition from fan-shaped to planar texture. (c): planar texture in cholesteric phase.

boundary of the fan-shaped texture begins to melt as shown in Figure 7(b). Then, the melting boundary changes into the net-like lines of the planar texture as shown in Figure 7(c). When the temperature is further increased, the whole of a cell changes to the transparent liquid phase.

The texture change in a cooling process from the liquid phase is shown in Figure 8. The focal conic texture coexisting with the liquid is observed at the transition temperature from the liquid phase to the cholesteric phase (Figure 8(a)). In a cholesteric phase, the focal conic texture is observed as shown in (b). As the temperature is further decreased to the smectic A, the focal conic texture changes into the fan-shaped texture as shown in Figure (c) and (d).

In the cooling process the focal conic texture appears in a cholesteric phase, because of remaining the disorder of the alignment in the liquid. It causes less transmission as compared with the planar texture in the heating process. In the high temperature side of a cholesteric phase, the mesh area is observed larger. This explains the characteristics of (iii) described at the beginning of this section.

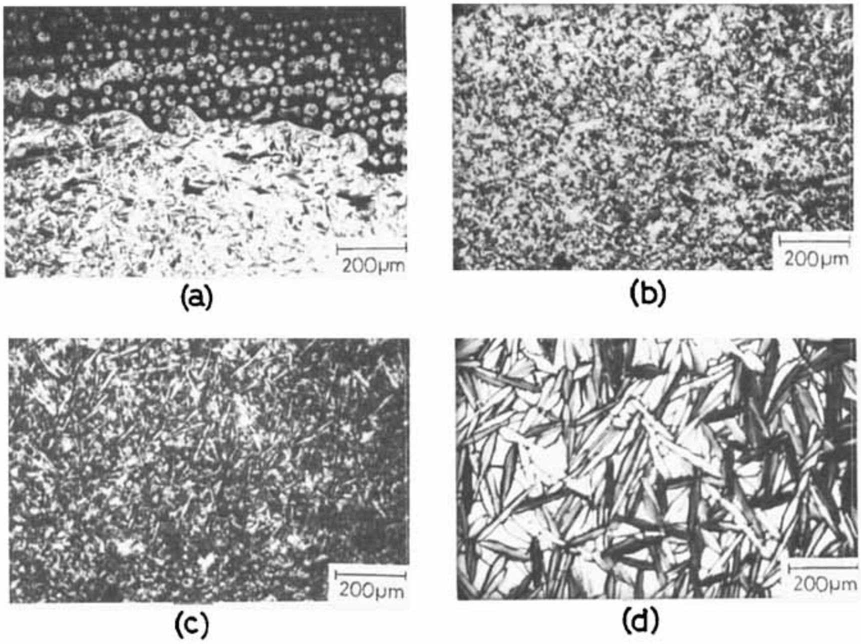

FIGURE 8 Texture change of smectic-cholesteric mixed liquid crystal from high to low temperature. (a): transition from liquid state to focal conic texture. (b): focal conic texture in cholesteric phase. (c) ~ (d): texture change from focal conic to fan-shaped texture.

4 CONCLUSIONS

We have investigated to interprete the variations in the light transmission of mixed liquid crystals from the viewpoint of the texture change. In the cholesteric phase of nematic-cholesteric mixed liquid crystal, the opaque state produced by the temperature variations cannot be recovered to the transparent state by high-frequency voltage, but low-frequency voltage is required prior to the high-frequency voltage. The transparent state in the smectic phase of smectic-cholesteric mixed liquid crystals changes abruptly to the opaque state in the cholesteric phase. These changes in light transmission through the mixed liquid crystals have been interpreted by the texture variations with the combination of the focal conic and the planar textures and that the difference in the light transmission of a planar texture depends on the mesh area: the larger the area is, the greater the transmission is.

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