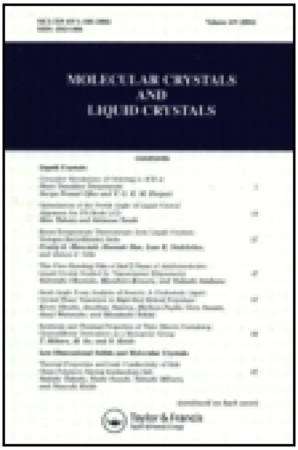


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# Optic Effects of Smectic-Cholesteric Mixed Liquid-Crystals†

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Light transmission characteristics in optic effects of smectic-cholesteric mixed liquid-crystals are experimentally investigated. Cholesteric addition to a smectic liquid crystal changes greatly transmission characteristics in a cholesteric phase. Although a smectic liquid crystal alone is transparent, the mixed liquid crystals become opaque. However, this opaque state is converted to the transparent state with applied fields. After the fields are removed, the transparent state is stored in case of the *n*-type mixture, *e.g.*, BBBA:CN = 90:10 in weight, but returns to the original opaque state in case of the *p*-type mixture, *e.g.*, COB:CN = 90:10 in weight. In the smectic phase, the *n*-type mixture hardly responds to applied fields, but the *p*-type mixture easily responds. The response is dependent on a cell temperature: higher field is required in lower temperature. This temperature characteristic can be used for display application of liquid-crystal light valve.

## 1 INTRODUCTION

Variations in light transmission through a liquid-crystal cell caused by temperature changes are very interesting phenomena in both of basic study associating with texture change and application to laser-addressed liquid-crystal display. In the application to display for a stored image, *p*-type smectic liquid crystals[1-3] such as CBOA (*p*-cyanobenzylidene-*p*-*n*-octylaniline) and COB (cyano-octyl-4-4′-biphenyl) have been mostly used.

We describe here experimental investigations on optic effects of (i) *n*-type smectic-cholesteric mixtures, and (ii) *p*-type smectic-cholesteric mixtures. Here, the terms *n*-type and *p*-type mean negative and positive dielectric anisotropy, respectively. The mixtures under investigations exhibit both a smectic and a cholesteric phase with raising temperature.

†The paper was presented at the Eighth International Liquid Crystal Conference, Kyoto, July 1980.

## 2 MEASUREMENTS

A schematic diagram for transmission measurements is shown in Figure 1. The thickness of a liquid-crystal cell is 12 $\mu$m, and the temperature of a whole cell was controlled in the temperature test chamber (Statham SD601). The photomultiplier was operated in a linear region of output voltage with respect to input light intensity. The maximum transmission in an isotropic phase was taken as 100% for a reference. The intensity of light guided through an optical fiber was so weak that the liquid-crystal temperature was not varied.

## 3 *n*-TYPE SMECTIC-CHOLESTERIC MIXTURES

The cell was prepared in homogeneous alignment with rubbing method. An *n*-type smectic liquid crystal such as BBBA (*p*-butoxybenzylidene-*p*-*n*-butylaniline) changes its phase from the smectic to the isotropic through the nematic with raising temperature. The light transmission varies little in all of smectic, nematic, and isotropic phases. However, the transmission was significantly decreased by cholesteric addition and exhibited the hysteresis as shown in Figure 2. This hysteresis can be illustrated in terms of texture hysteresis: the planar texture with net-like lines (mesh-like texture) in the heating process and the focal conic texture in the cooling process.[4,5] The net-like lines can be understood as the interface at which the direction of molecular axis changes abruptly, and thus they scatter light. The decrease in transmission is proportional to amount of cholesteric, but saturated near 10% addition. Beyond this, the coloring of a cell was observed. The transition temperatures of sample materials are summarized in Table I where the subscripts *S*, *N*, *C*,

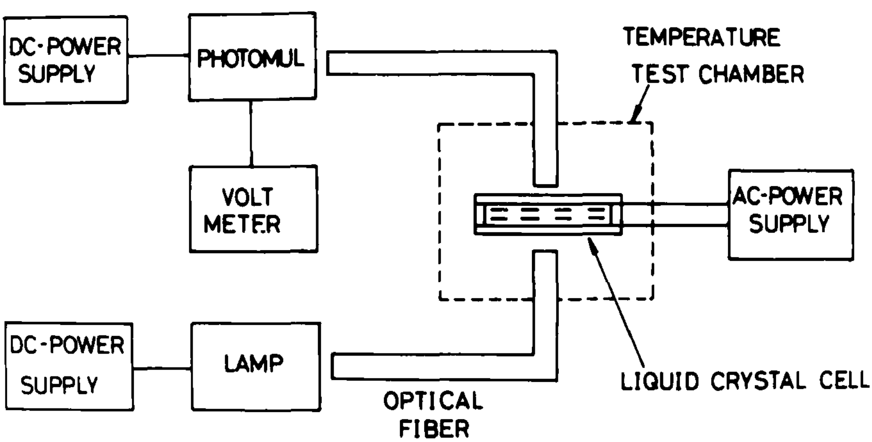


FIGURE 1 Schematic diagram for transmission measurement.

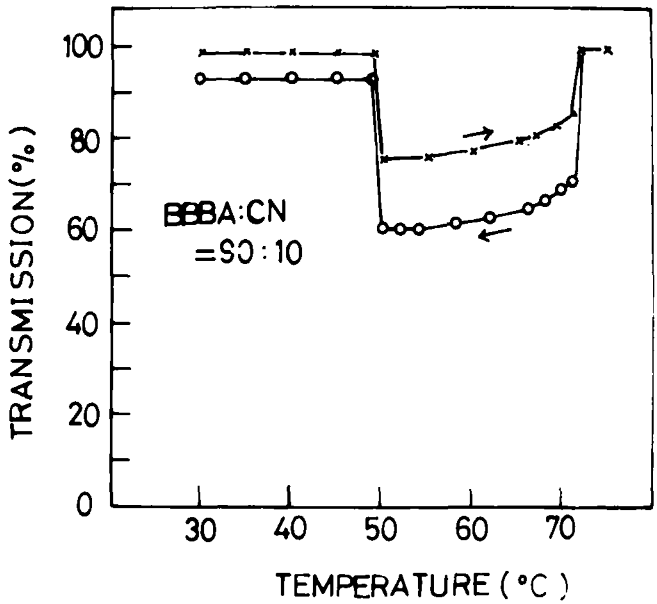


FIGURE 2 Transmission characteristics in thermo-optic effects of *n*-type smectic-cholesteric mixture.



and $I$ denote smectic, nematic, cholesteric, and isotropic, respectively. Thus, for an example, the $T_{SN}$ means the transition temperature between the smectic and the nematic phases.

Temperature dependence of transmission through a cell subjected to applied fields is shown in Figures 3 and 4. As compared Figures 3(a), (b), and (c) with Figure 2, the transmission is recovered in a lower temperature side of the cholesteric phase, but lowered in a higher temperature side. It is considered

TABLE I

Transition temperatures of sample materials.

| | $T_{SN}$ | $T_{NI}$ |
|---|---|---|
| BBBA | 50 | 74 |
| COB | 34 | 41 |

| | $T_{SC}$ | $T_{CI}$ |
|---|---|---|
| CN | 78 | 91 |
| BBBA:CN (9:1) | 49.2 | 72.2 |
| COB:CN (9:1) | 34 | 44 |

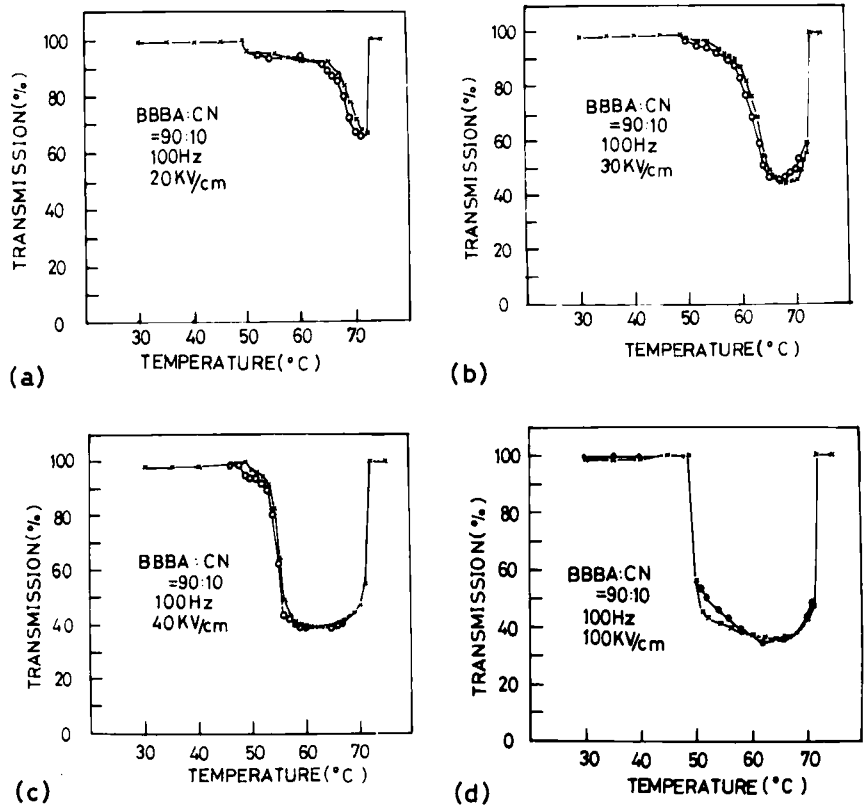


FIGURE 3 Transmission characteristics in electrothermo-optic effects of *n*-type smectic-cholesteric mixture, with constant applied frequency 100 Hz.

that with the applied field the texture approaches to a uniform planar texture in a lower side and that the electrohydrodynamic instability of the conducting regime occurs in a higher side.[6,7] The values of elastic constants of the liquid crystal materials become larger at a lower temperature in a cholesteric phase. Thus, the threshold field for the instability[8] becomes greater, *e.g.*, as shown in Figure 3(a), the field intensity 20 KV/cm is not large enough below 65° C, but it is sufficiently large above 65° C.

With increasing frequency, the transmission is gradually increased from a lower temperature side as shown in Figure 4. It results from that the instability changes from conducting regime to dielectric regime with increasing frequency.[6,7]

In Figure 5, the influence of cholesteric addition on the transmission variations is shown for some other smectic liquid crystals: HBBA (*p*-hexoxybenzylidene-*p*-*n*-butylaniline), PBPA (*p*-pentoxybenzylidene-*p*-*n*-pentylaniline),

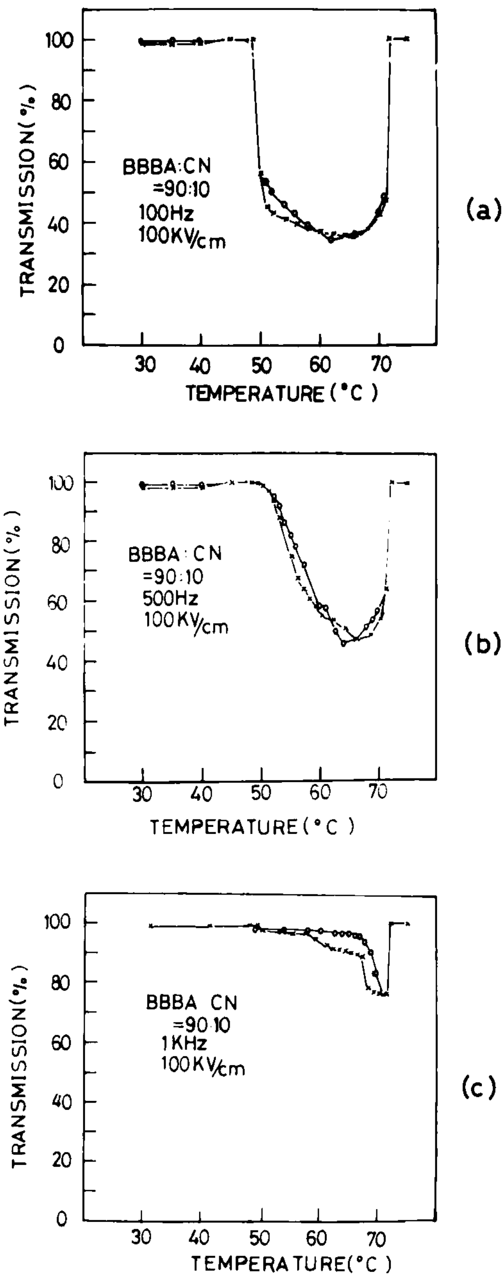


FIGURE 4 Transmission characteristics in electrothermo-optic effects of *n*-type smectic-cholesteric mixture, with constant intensity of applied field 100 KV/cm.

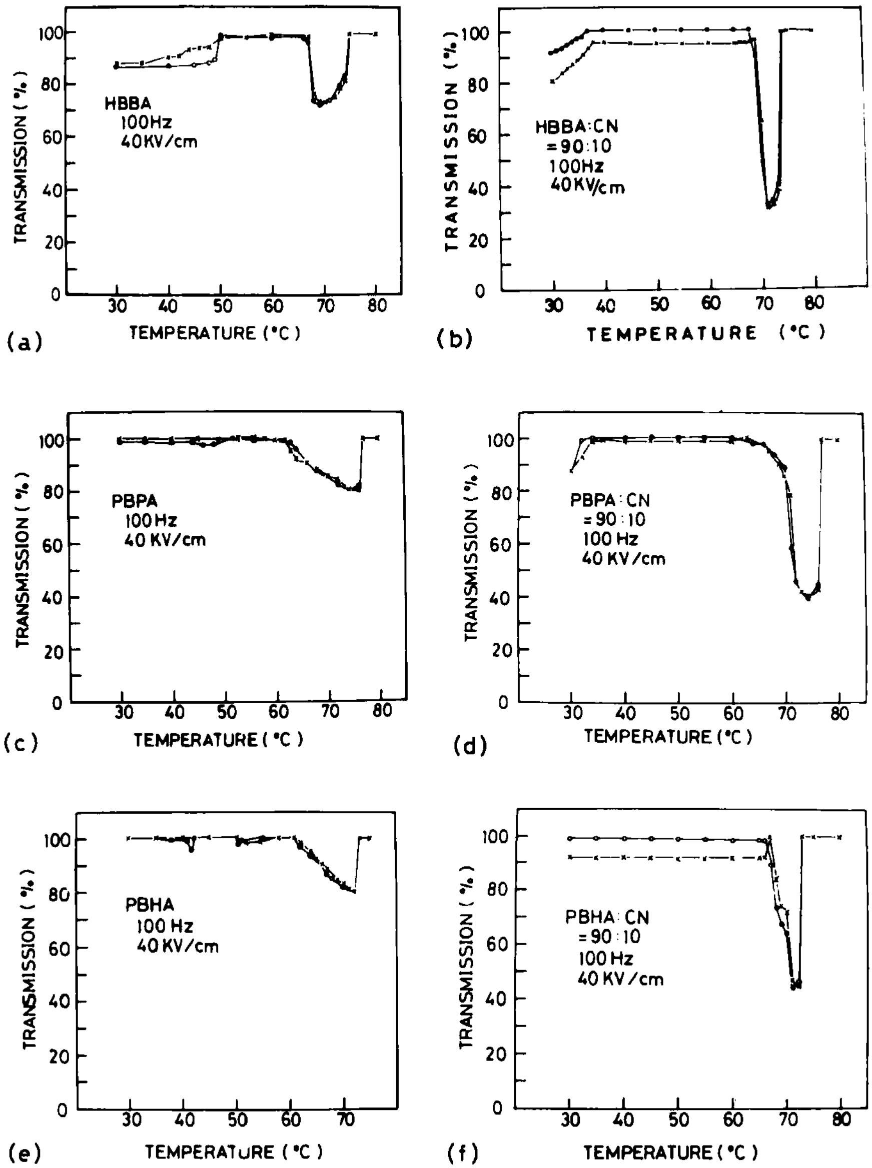


FIGURE 5 Transmission characteristics in electrothermo-optic effects of n-type smectic liquid crystals and their mixtures with cholesteryl nonanoate.

and PBHA (*p*-pentoxylbenzylidene-*p*-*n*-hexylaniline). For reference, the temperature dependence of transmission through BBBA subjected to applied field is shown in Figure 6. It is seen in Figure 5, similarly in Figure 6 as compared with Figure 3(c), that cholesteric addition enhances transmission variations.

Except for HBBA, with raising temperature the transmission begins to decrease at the transition temperature from the smectic to the cholesteric phase, and then decreases gradually until the transition temperature to the isotropic phase (liquid), as seen for BBBA, PBPA, and PBHA. However, interpretation to these temperature dependent characteristics is not available at the present.

The abrupt change in transmission, as observed in HBBA:CN, is desirable for a fast operation of laser-addressed display, because a large contrast ratio can be obtained with small temperature variation.

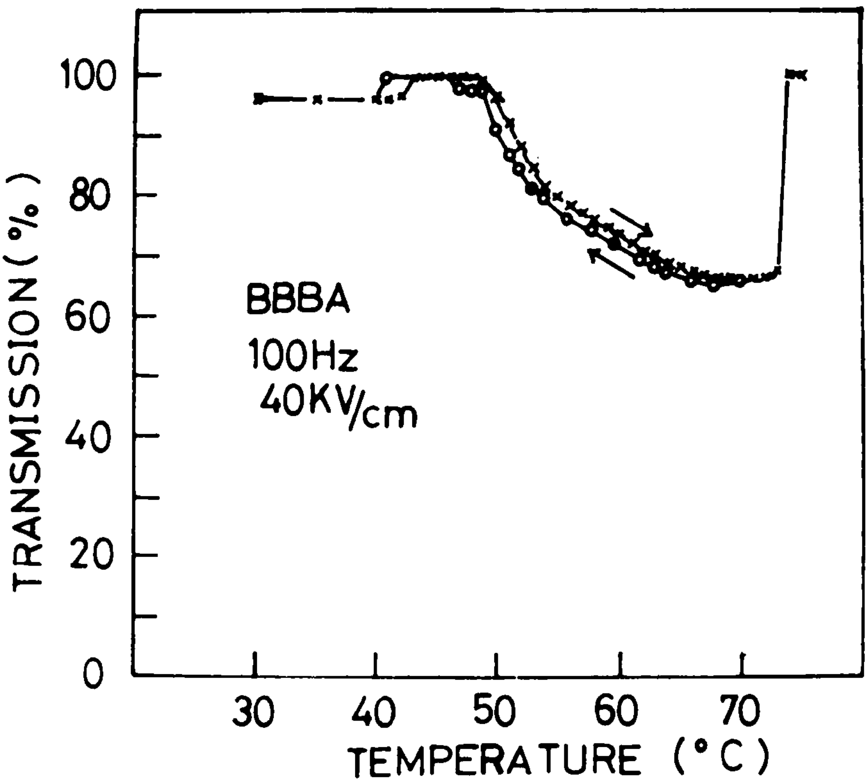


FIGURE 6 Transmission characteristics in electrothermo-optic effects of BBBA.

## 4 p-TYPE SMECTIC-CHOLESTERIC MIXTURE

The substrate surface of a cell was treated with CTAB (cetyl trimethyl ammonium bromide) for a homeotropic alignment. As shown in Figures 7(a) and (b), transmission through the mixture of p-type smectic liquid crystal COB cyano-octyl-4-4′-biphenyl and cholesteric liquid crystal CN (cholesteryl nonanoate) is decreased in the cholesteric phase, although COB itself changes little in all of smectic, nematic, and isotropic phases similar to n-type smectic liquid crystal. The measurements of transmission were carried out with applied field 10 KV/cm where the unstable flow pattern was observed under microscope (Figure 8). The transmission decrease caused by the unstable molecular flow[9] is reduced with increasing frequency. It would be resulted from that molecules respond harder to a higher frequency. With about 20 KV/cm application, the phase transition occurs as described in the next section.

## 5 TRANSMISSION CHARACTERISTICS OF ELECTRO-OPTIC EFFECTS

The BBBA:CN mixture responds to applied fields differently from the COB:CN mixture. An opaque focal conic texture in a lower temperature side

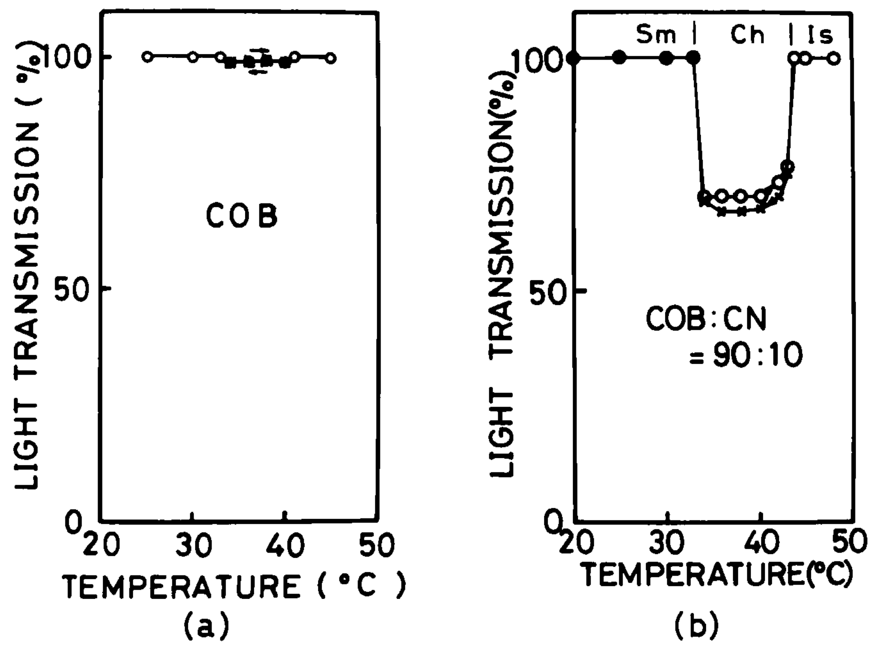


FIGURE 7 Transmission characteristics in thermo-optic effects of COB and COB:CN.

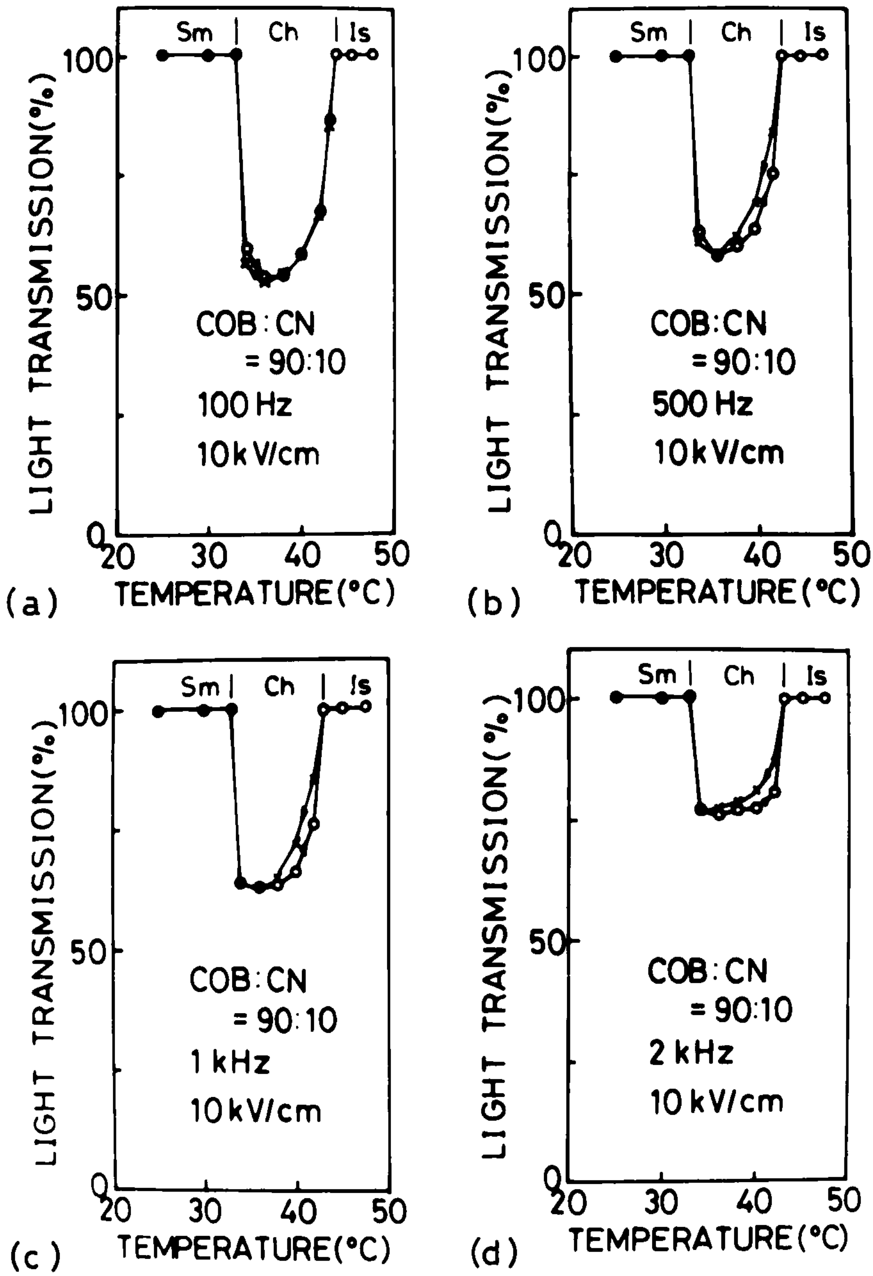


FIGURE 8 Frequency dependence of transmission characteristics of electrothermo-optic effects of COB:CN.

of a cholesteric phase in Figure 2 becomes a transparent planar texture (Figure 4(c)) with a high-frequency applied field. Then, the liquid crystal is retained in the transparent state after removing the field. Starting at this transparent state, we measured the transmission variations with applying a low-frequency field. The light scattering state caused by the electrohydrodynamic instability in the conducting regime is not stored as shown in Figure 9. This characteristic is contrary to that of the mixture of MBBA, EBBA, and CN where the storage effect was measured.[5] The HBBA:CN mixture also exhibits the storage effect.

Maintaining in the transparent smectic phase a whole cell of $n$-type smectic-cholesteric mixture, we heat a local portion of the cell and cool to the original temperature. Although the texture has to be confirmed, the focal conic texture



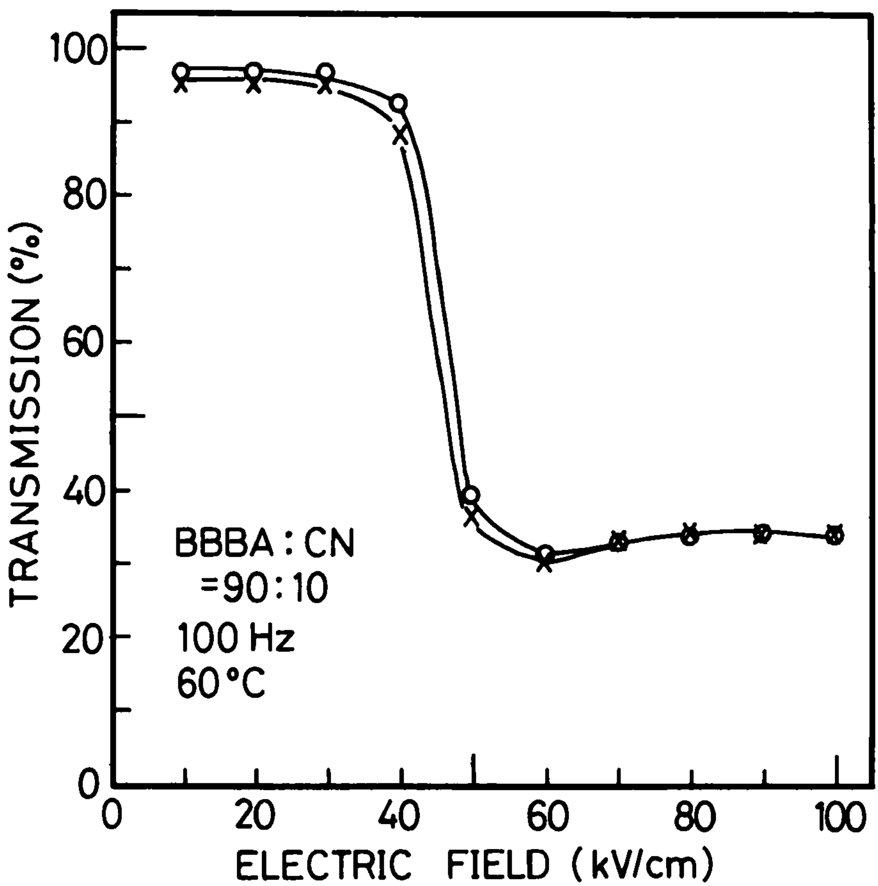


FIGURE 9 Transmission characteristics in electro-optic effects of BBBA:CN. The light scattering state is not stored in the cholesteric phase.

yielded in the cholesteric phase is frozen and stored in the smectic phase, and thus the local portion becomes opaque. This opaque state in the smectic phase has not been successfully converted to the transparent state with an applied field. It suggested that the stored image (focal conic texture) in the smectic phase cannot be easily erased with the field.

The transmisssion variations, caused by applied fields of COB: CN mixture in the cholesteric phase are shown in Figure 10. The transmission minimum around 10 KV/cm application is increased with frequency. It is the same phenomenon as given in Figure 8. Figure 10 shows that the texture change from the opaque focal conic to the transparent homeotropic, *i.e.*, from the cholesteric to the nematic phase occurs and that the transparent nematic phase does not remain at a zero field. However, in the smectic phase, the transparent state converted from the focal conic texture remains as shown in Figure 11. On the contrary to the *n*-type mixture, with these characteristics of *p*-type mixture a whole stored image in the smectic phase can be successfully erased in the display application:[2,3] the opaque state in the smectic phase can be converted to the transparent state. The temperature dependent characteristics in Figure 11 are very important for the liquid-crystal light valve of multifunction operation such as simultaneous display for static and dynamic figures.[10]

In a laser-addressed light valve of smectic liquid crystals, the temperature increase from the smectic phase to the isotropic phase through the nematic phase has to be given for creating light scattering centers of honeycomb texture.[11] Following the present investigation of the optic effects of smectic-cholesteric mixed liquid crystals, the light scattering centers of focal conic texture can be created by the temperature increase only from the smectic phase to the cholesteric phase. Thus, faster writing capability can be expected in smectic-cholesteric system.[12]

## 6 CONCLUSIONS

We have experimentally investigated optic effects of smectic-cholesteric mixed liquid crystals. The results can be summarized in the following:

(1) Light tranmission through a smectic cell varies little in all of smectic, nematic and isotropic phases. However, transmission is lowered significantly in a cholesteric phase with cholesteric addition.

(2) The decrease in transmission is enhanced by electrohydrodynamic instability in the conducting regime caused by an applied field.

(3) With a high-frequency applied field, the opaque focal conic texture in the cholesteric phase is converted to the transparent planar texture in case of *n*-

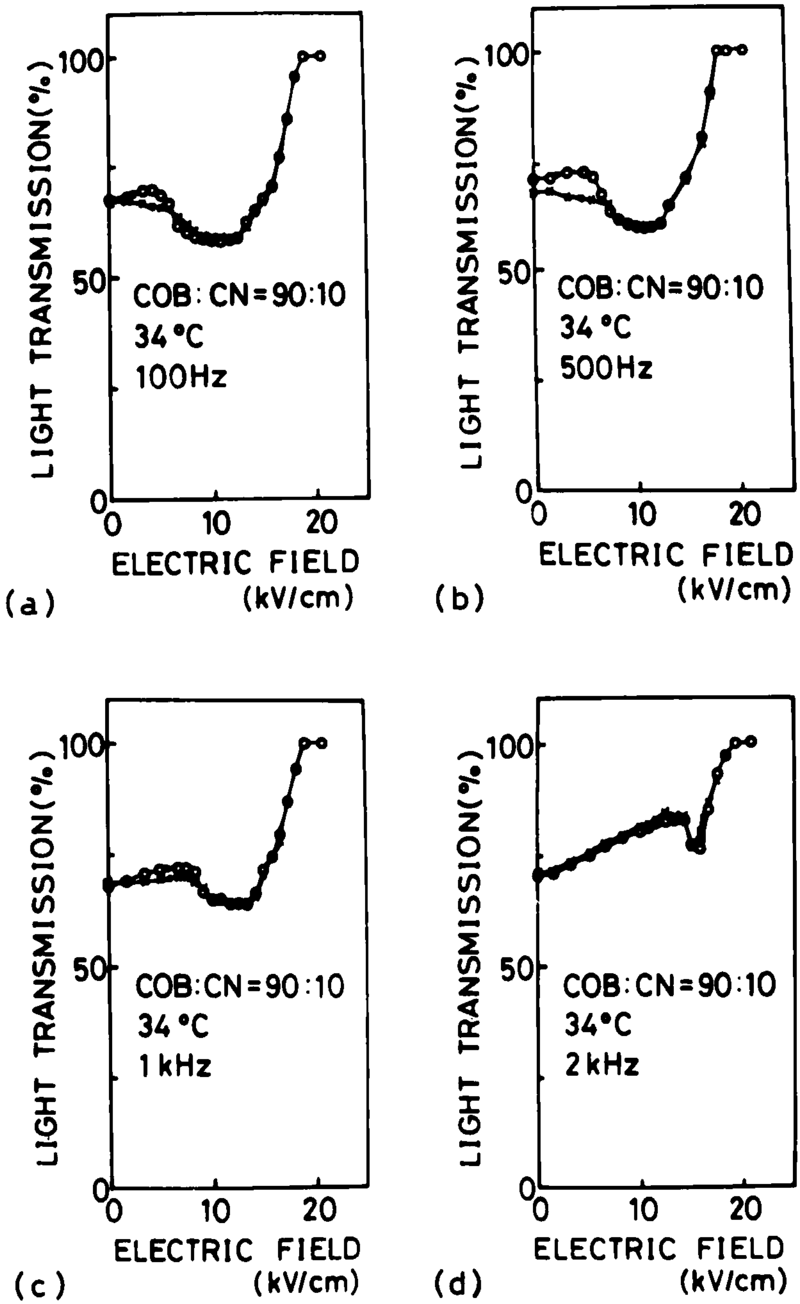


FIGURE 10 Frequency dependence of transmission in electro-optic effects of COB:CN in cholesteric phase.

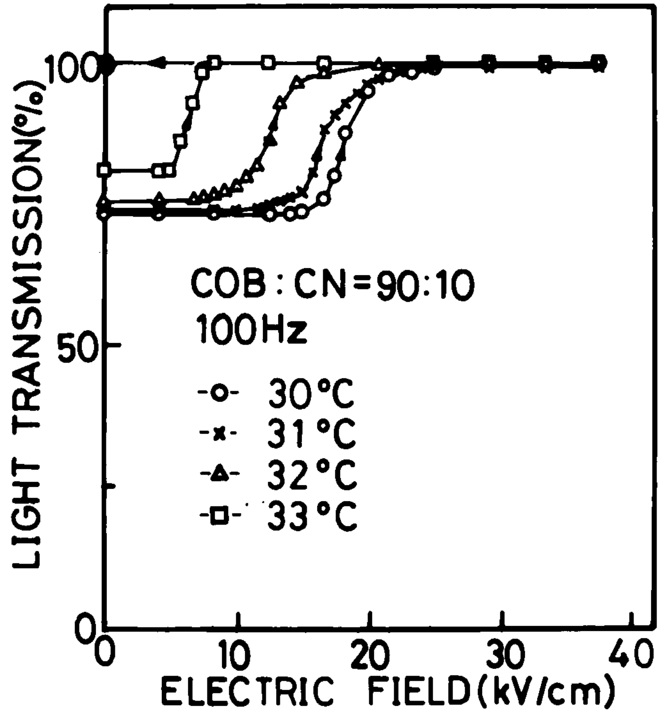


FIGURE 11 Temperature dependence of transmission in electro-optic effects of COB:CN in smectic phase.

type smectic-cholesteric mixture and to the transparent homeotropic texture (nematic phase) in case of *p*-type smectic-cholesteric mixture. In the latter mixture, the texture transition occurs also with a low-frequency applied field. After the field is removed, the transparent state remains in an *n*-type mixture, whereas it returns to the opaque state in a *p*-type mixture.

(4) The opaque focal conic texture in the smectic phase of the *n*-type mixture hardly responds to the applied field, but that of the *p*-type mixture is converted to the transparent homeotropic smectic texture which remains in the smectic phase at zero field.

(5) The threshold field for the conversion depends on the cell temperature: higher field is required in lower temperature of a cell.

Since the mixture is not an essential point for the optical effects described here, a single compound liquid crystal exhibiting a smectic and cholesteric phase would behave in similar ways. Application of these characteristics of smectic-cholesteric mixed liquid crystals to display will be reported in the future.

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