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Cross-sectional observations of the cholesteric texture in a Cano wedge cell

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A novel procedure for an observation of a liquid crystal texture is proposed by using a UV curable liquid crystal. Optical observations from a cross-section of the Cano wedge cell are demonstrated and layered structures of cholesteric LC are visualized clearly. The structures near the Grandjean lines are then revealed in detail from images. From the observations, it is confirmed that the texture near the Grandjean line is similar to fingerprint texture

1. Introduction

Recently, UV curable liquid crystal (LC) materials have been synthesized [1] and are receiving great attention as novel LC materials. They have a nematic phase at room termperature, and can be photo-polymerized by ultraviolet (UV) light irradiation. So far, an optical phase-controlling component using this material has been developed in order to decrease the dependence of viewing angles in LC display panels [2]. As a micro-optic device, a UV cured LC microlens array has been fabricated in which an inhomogeneous electric field produced by a hole-patterned electrode structure is applied during the UV curing process [3]. It is confirmed that relatively good optical properties can be obtained. Since this material shows a nematic phase before photo-polymerization, conventional LC technologies can be employed to fabricate these devices. Furthermore, the optical properties of the devices can easily be adjusted by applying a voltage before photo-polymerization. This feature seems to be useful for device fabrication.

A method for observing the molecular organization in a cross-section of a LC cell has been proposed by de Gennes [4] in order to clarify the complicated cholesteric texture near a Grandjean line. He suggests using a liquid crystalline material such as a cholesteric acrylate [4]. In practice, Heynderickx *et al.*, observed the twisted structure near the Grandjean line in a cholesterically ordered liquid crystalline network by using scanning electron microscopy (SEM) [5]. This observation revealed a layered structure in the cross-section of the cell. Unfortunately, it is difficult to understand the layered structure near the Grandjean lines in detail since the cross-sectional images are unclear.

We have proposed and demonstrated a novel observation method to investigate the molecular orientation in a cross-section of a LC cell by using a UV curable LC material [6]. This procedure allows us to visualize continuous director distributions and structures of disclination lines in the cross-section of the cell. This observation method seems, therefore, to be useful for understanding the mechanism by which disclination lines are formed and for clarifying various types of complicated LC textures which have helical structures.

In this paper, we elucidate the cholesteric texture near the Grandjean lines in a cross-section of a Cano wedge cell [7] by using a UV curable LC material.

2. Experimental

Grandjean lines were produced by using the Cano wedge method [7]. PVA (polyvinylalcohol)-coated glass substrates were used to fabricate the wedge-shaped LC cell and the substrates were rubbed to give a homogeneous molecular orientation. The UV curable LC material, Mixture E (from Dainippon Ink and Chemicals, Inc.) containing 9 wt% chiral dopant (C15, Merck) was used in this work. The cell gap was controlled by a glass plate of thickness 120 μm, which was inserted in one side between the substrates. The angle of the wedge was 0·7°. The UV curable LC in the wedge-shaped LC cell was photo-polymerized by UV irradiation. The irradiation intensity and time were 1 mW cm^{-2} and 120 s, respectively.

A specimen for the observation was cut from the cured wedge-shaped LC cell so that the cutting plane was perpendicular to the Grandjean lines, and it was lapped until the thickness became less than 50 μm in order to

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obtain transmission images from the cross-section of the cell. Cross-sectional transmission images of the specimen were observed optically by using a microscope. Here, a tungsten lamp was used as a light source and the incident light was polarized in a direction normal to the helical axis.

3. Results and discussions

Figure 1 shows the transmission image of the wedge-shaped LC cell after photo-polymerization. Periodically appearing disclination lines can be seen in the wedge-shaped LC cell under the boundary condition that the molecules on both the substrates are aligned parallel to one another. These lines are attributed to the chiral pitch of cholesteric media.

The period of the disclination lines did not change during the photo-polymerizing process and is 350 μm here. This fact shows that the molecular orientation state in the cell is not affected by the photo-polymerization. The relation between cholesteric pitch p and the distance between the disclination lines d is approximately given by $p=2d\theta$, where θ is the angle of the wedge-shaped cell [8]. Hence, we get a value of 8·5 μm for the cholesteric pitch p in this case.

These periodically appearing disclination lines, called Grandjean lines, horizontal χ-lines, or edge-dislocations, were first observed by Grandjean [9]. Their structures and molecular orientation states are explained by Zocher, Cano and Scheffer [7, 10, 11]. Scheffer has shown that χ-lines are unstable and tend to split into pairs of τ- and λ-lines. Figure 2 shows some examples of pairing of λ- and τ-lines of opposite signs in cholesteric liquid crystals [8]. It is found that χ-lines dissociate into edge dislocations (*a*) $\lambda^-\lambda^+$ pair, (*b*) $\tau^-\tau^+$ pair, (*c*) $\tau^-\lambda^+$ pair and (*d*) $\lambda^-\tau^+$ pair, of figure 2 respectively.

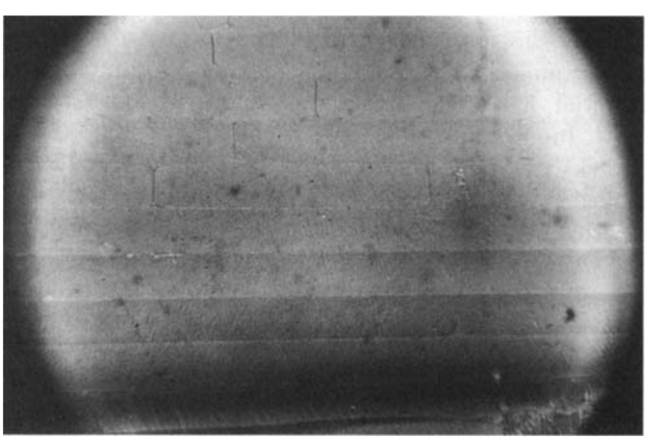

Figure 1. The transmission image of the wedge-shaped cell after the photo-polymerization.

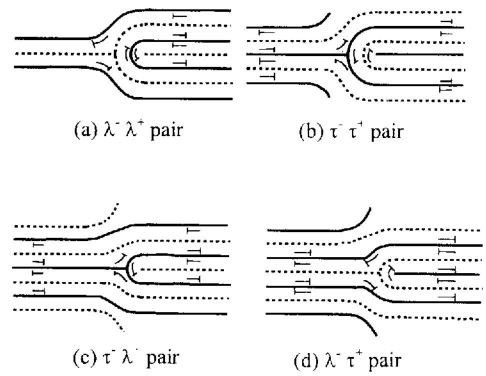

Figure 2. Examples of pairing λ- and τ-lines of opposite sign in a cholesteric LC.

Figure 3 (*a*) and (*b*) show cross-sectional transmission images of the wedge-shaped LC cell. As shown in the figures, narrow stripes of cholesteric layers can be observed clearly. It seems that the dark and bright stripes display the cholesteric layered structures. The bright stripes correspond to the solid lines shown in figure 2. This texture seems to be similar to a fingerprint texture, and the edge dislocation occurs in the middle of the LC cell. Provided that the period of a layer shown in figure 3 (*a*) equals π, the defect is located at the boundary between a total molecular twist of 10π and 11π. Since the observed layer spacing is about 5 μm, the cholesteric pitch is determined to be 10 μm. This value almost corresponds to the calculated value. This edge dislocation corresponds to the cross-sectional image of the Grandjean line. It seems that a new banded layer is formed between two banded layers at the region where the edge

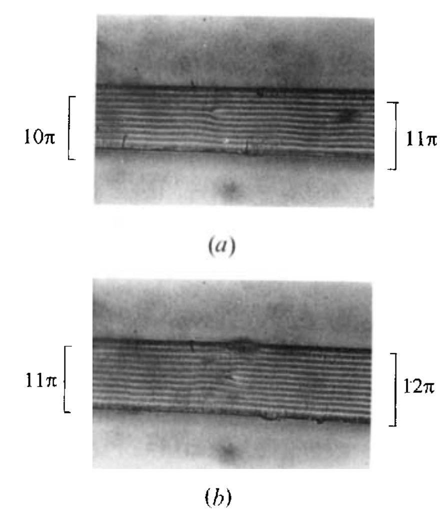

Figure 3. The cross-sectional transmission images near the Grandjean line. The edge dislocation of strength $\frac{1}{2}$ dissociated into a $\tau^-\lambda^+$ pair (*a*) and a $\lambda^-\tau^+$ pair (*b*) respectively, can be observed.

dislocation occurs. Therefore, in this case the Grandjean line of strength $\frac{1}{2}$ appears and it tends to dissociate into a $\tau^- \lambda^+$ pair. This texture is the same as that shown in figure 2 (*c*).

In figure 3 (*b*), the edge dislocation is also found at the boundary between a total molecular twist of 11π and 12π. As shown in the figure, the banded layer at the edge dislocation to the left-hand side of the discontinuity seems to split into two new banded layers. Hence, the Grandjean line of strength $\frac{1}{2}$ has dissociated into a $\lambda^- \tau^+$ pair. This texture corresponds to that shown in figure 2 (*d*).

As the cell thickness increases, curious edge dislocations are observed and are shown in figure 4 (*a*)–(*c*). These appear to be edge dislocations and lie opposite to each other. These edge dislocations seem to be a Grandjean line of strength 1 dissociated into a $\tau^- \tau^+$ pair (see figure 4 (*a*)) and one of strength 1 dissociated into a $\lambda^- \lambda^+$ pair (see figure 4 (*b*)). These edge dislocations seem to correspond to the texture shown in figures 2 (*b*) and (*a*), respectively. Moreover, it is seen that two edge dislocations lie one upon another as shown in figure 4 (*c*). Since these edge dislocations do not dissociate into pairs of τ- and λ-lines, curious edge dislocations which do not correspond to the texture shown in figure 2 are observed in these figures. The reasons seem to be that it takes a long time to achieve a stable state, and the molecules in the middle of the cell are not effected by the boundary condition of the rubbed substrate since the cell thickness is larger.

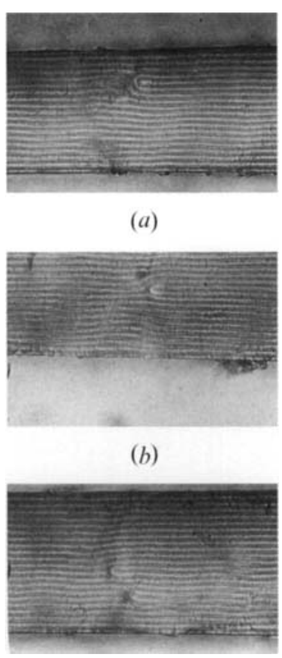

Figure 4. The cross-sectional transmission images of near the Grandjean line. The edge dislocation of strength 1 dissociated into a $\tau^- \tau^+$ pair (*a*) and a $\lambda^- \lambda^+$ pair (*b*) respectively, occur. Two edge dislocations are observed in (*c*).

4. Conclusions

In this study, we have observed cross-sectional images of the Cano wedge cell. The structures near the Grandjean lines are visualized optically for the first time and edge dislocations dissociated into paris of τ- and λ-lines were observed in detail by using this procedure. It is confirmed that the texture of the cross-sectional images near the Grandjean lines is similar to a fingerprint texture. This observation method is useful in revealing the complicated LC textures which have yet to be fully understood.

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