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# Visualization of Director Distributions from the Cross-Sectional Images Using A Dye Doped UV Cured Liquid Crystal Cell

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# VISUALIZATION OF DIRECTOR DISTRIBUTIONS FROM THE CROSS-SECTIONAL IMAGES USING A DYE DOPED UV CURED LIQUID CRYSTAL CELL

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Abstract Cross-sectional observations of liquid crystal (LC) cells using a dichroic dye doped UV curable LC are demonstrated. The cross-sectional director distributions in LC cells are calculated using an absorption of the dichroic dye with the same direction of LC. As the results, we can successfully visualize the director distribution in the cross section of the LC cell.



## INTRODUCTION

Investigation of the director distribution in the liquid crystal displays(LCDs) and the structure of the disclination lines are important to improve the display performances. As increasing resolution and complicating pixel electrode structures of the LCDs, disclination lines across the pixel electrodes produced by the complicated electrode structures influence the electro-optical properties and restrict the display performances. Recently, two- or three-dimensional computer simulations in the LCDs have been demonstrated to visualize the director distribution and the structure of disclination lines.[1,2] The electro-optical performances of the LCDs have been successfully explained from the molecular orientation states.

Besides, visualization of textures and defects in LCs have been shown experimentally using liquid crystalline polymers (LCP). The director distributions near the defects and their structures have been revealed using AFM (Atomic Force Microscopy) through the lamellar decoration technique.[3] The director distribution of the frozen LCP can be determined by the microstructure of the lamellae, which is the same length scale as that of polymer molecules. Furthermore, the cross-sectional observation of the twisted structure near the Grandjean line in a cholesterically ordered liquid crystalline network have been shown using scanning electron microscopy.[4]

We have proposed and demonstrated a novel cross-sectional observation method[5,6] to visualize the director distribution in the LC cells using a UV curable LC material.[7] The feature of this technique is that continuously changing director distribution states of the practical LC devices can be visualized from a cross section. In this work, the cross-sectional images of the LC cell are observed and their director distributions are elucidated from the distribution of the transmission light intensity through the cured LC specimens using a dichroic dye doped UV curable LC material.



## EXPERIMENTAL

To investigate the cross-sectional director distribution in the LC cell, a bend cell[8] was prepared using ITO-coated glass substrates coated with PVA(polyvinylalchohol). The surfaces of the substrates were treated by rubbing in parallel directions. The cell thickness was controlled using glass rod spacers (40μm). The UV curable LC material with a positive dielectric anisotropy, Mixture E (from Dainippon Ink and Chemicals, Inc.) containing 1 wt% of a dichroic dye (Nippon Kayaku, Co., Ltd.) was used in this work. This material shows a nematic phase at room temperature before the photopolymerization. The UV curable LC material was put into the cell by using capillary action and was photopolymerized by UV irradiation (1 $mW/cm^2$ and 120 s) with applying an AC voltage.

An LC cell with a stripe-patterned electrode structure was fabricated to determine the continuously changing director distribution. Figure 1 shows the LC cell with the stripe-patterned electrode structure. The stripe-patterned electrode was prepared by photolithographic etching of the ITO-coated glass substrate. A width of the striped pattern electrode and a cell thickness was 2 mm and 40 μm, respectively. The rubbing direction was perpendicular to the stripe pattern in antiparallel directions. The dichroic dye doped UV curable LC was filled into the cell, then it was photopolymerized with applying the electric field produced by the stripe-pattern electrode structure.

To investigate the cross-sectional director distribution, these LC cells mentioned above were cut into slices in the rubbing direction and made thin until its thickness of the specimens became less than 50 μm. This procedure enables us to observe the cross-sectional director distribution of the LC cell. The sliced specimens were observed using a polarizing microscope connected with a CCD camera.

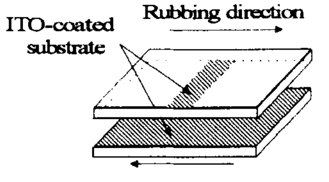


FIGURE 1 Device structure of the LC cell with a stripe pattern electrode.

## RESULTS AND DISCUSSION

Figure 2(a) and (b) show the cross-sectional transmission images of a cured bend cell under crossed polarizers. The specimen was photopolymerized with applying an AC voltage of 8 $V_{rms}$. As shown in Fig. 2(a), the cross-sectional transmission light intensity through the cured LC layer decreases in the middle of the LC layer and it becomes gradually bright as getting close toward the upper and lower substrates. The molecules in the middle of the cured LC layer begin to tilt up toward the electric field and the directors in this area correspond to the polarization direction of the analyzer. To determine the director distribution near the substrate, the specimen was observed with rotating under crossed polarizers. Figure 2(b) shows the cross-sectional image with

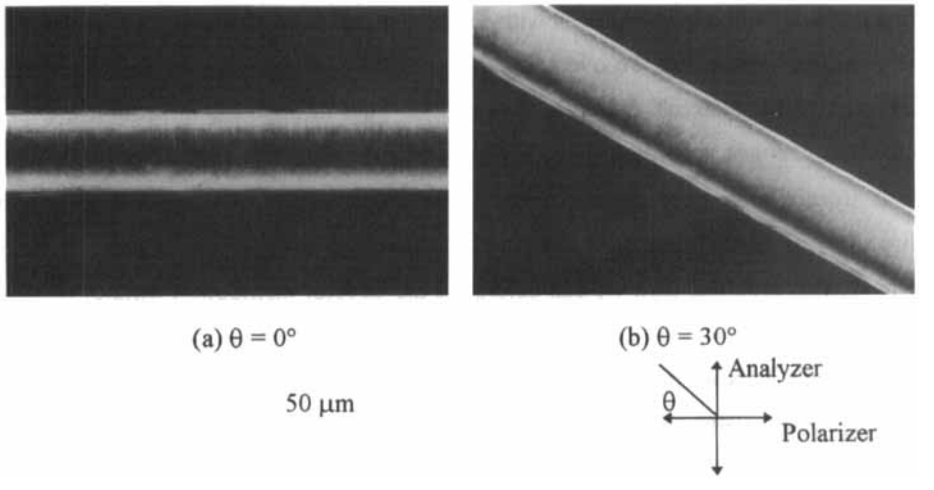


FIGURE 2 Cross-sectional transmission images of the cured Bend cell photopolymerized with applying AC voltage of 8 $V_{rms}$.

rotating the specimen. As rotating the specimen, a lower side of the transmission intensity in the cured LC layer becomes dark. This is because the directors in the dark region correspond to the polarization direction of the polarizer and the molecules near the upper and lower substrates are tilted in the opposite direction. Hence, the bend molecular orientation can be confirmed by the cross-sectional observation. This optical observation under crossed polarizers is useful for the visualization of the cross-sectional director distribution of the LC cell with a simple electrode structure such as the plane parallel electrode structure. On the other hand, determination of the director distribution in a complicated electrode structure, which produces inhomogeneous electric fields, seems to be difficult since the molecules in the LC layer continuously change their direction by the nonuniform electric field. The transmission light intensity through the specimen (I) changes as following equation[9]

$$I \propto \sin^2(2\phi)\sin^2(2\pi\Delta nd/\lambda), \qquad (1)$$

where $\phi$ is an angle between polarization direction of the polarizer and the directors and $\Delta n$ is birefringence of a material, d shows a thickness of the specimen and $\lambda$ is a wavelength of the incident light. From this equation, it is obviously understood that the transmission light intensity through the specimen changes periodically according to the angle $\phi$. The angle $\phi$ from the dark transmission state to the bright state is 45° under crossed polarizers. Therefore, we can hardly determine the continuously changing director distribution in the LC cell with a complicated electrode structure and also that near the disclination line. To overcome this problem, we utilize the dichroic dye doped UV curable LC material. Since the transmission light through the dichroic dye doped specimen changes according to an anisotropy of the light absorption, the angle from dark transmission state to the bright state becomes 90°. We assume that both directions of the LC and dye molecules indicate the same direction in the LC cell to simplify this problem, then we can determine the director distribution without rotating the specimen.

Figure 3 shows the cross-sectional director distribution calculated from a cross-sectional image using the dichroic dye doped UV curable LC material. We assume that the molecules near the substrate tilted up in the opposite direction from the results mentioned above. From this result, we can successfully visualize the director distribution from the cross-sectional transmission light intensity through the specimen.

Figure 4(a) shows the cross-sectional transmission image of the continuously changing director distribution near the edge of the electrode in the LC cell with the stripe-patterned electrode structure. The dichroic dye doped UV curable LC material was used and the specimen was observed using a polarizing microscope without a polarizer so as to have unpolarized incident light, but the analyzer was used. The transmission light intensity through the specimen continuously distributes in the cured LC layer. Almost molecules under the top electrode tilted up uniformly, while the molecules in the left side of the top electrode are continuously changed their directions by the inhomogeneous electric field. From this image, the director distribution in the cured LC layer is converted to the light intensity and it can be calculated based on the anisotropy of the absorption in a dichroic dye. Figures 4(b) shows the director



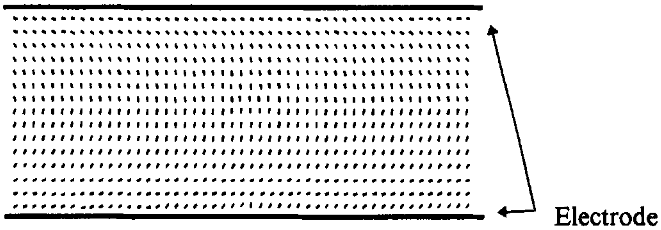


FIGURE 3 The cross sectional director distribution of the bend cell calculated from the transmission image of the sliced specimens using dichroic dye doped UV curable LC.

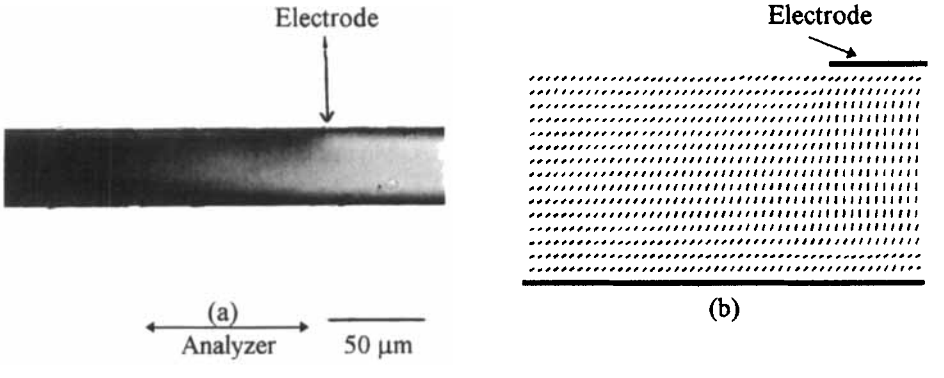


FIGURE 4 The cross-sectional transmission image of the continuously changing director distribution in the LC cell with the stripe-patterned electrode structure photopolymerized with applying AC voltage of 14.5 $V_{rms}$ (a) and the director distribution near the edge of the electrode calculated from the cross-sectional image(b).

distribution near the edge of the electrode calculated from the light intensity through the specimen. In these figures, it is found that the directors near the edge of the electrode incline toward the nonuniform electric field. From this result, the continuously changing director distribution in the LC cell can be displayed in practice by the cross-sectional image.



## CONCLUSIONS

In this study, the cross-sectional observations of the cured LC cell are demonstrated using the dichroic dye doped UV curable LC material. The cross-sectional images of the specimens are observed clearly and the transmission light intensity is converted to the director distribution by using an anisotropy of the absorption of the polarized light through the dichroic dye doped cured LC specimens. We can successfully visualize the director distribution in the cross section of the LC cell without rotating the specimen. This method is also useful for the investigation of the defects in liquid crystal cells.

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