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Uniform Lying Helix of Cholesteric Liquid Crystals Aligned by means of Slit Coater Method with Electric Treatment

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SUMMARY A Uniform Lying Helix (ULH) liquid crystal device (LCD) fabricated by utilizing the characteristics of shear flow alignment as well as dielectric anisotropy was demonstrated. Cholesteric liquid crystals with a short helical pitch can exhibit an electric field-induced tilt. These experimental results indicate that it is possible to realize a high-speed response flexible LCD using plastic substrates.

key words: *uniform lying helix mode, flexible LCD, slit coater, short-pitch cholesteric liquid crystals*

1. Introduction

The Uniform Lying Helix (ULH) is expected to be a next-generation Liquid Crystal Display (LCD). Previously, a fast-switching effect that exhibits an in-plane rotation of the optical axis has been reported [1]–[10], which is advantageous in wide-viewing angle and high-definition video formats. At present, however, a suitable technique for achieving perfect liquid crystal (LC) alignment of ULH has not yet been established. Various methods involving a combinations of mechanical, thermal, and electric field cycling [1], [2], [5], a periodic anchoring condition [8], electro-hydrodynamic effects using materials with high dielectric anisotropy [9], and tri-electrodes configuration [10] have all been used with some effectiveness. We have recently proposed a slit-coating method as a novel fabrication process for flexible LCDs [11]–[14]. The most appealing feature of the slit-coating method is that an alignment film, such as polyimide, is unnecessary. Therefore, the slit-coating method has the potential to simplify the LCD manufacturing process and can be applicable to plastic substrates for flexible LCDs. Previously, it was found that a ULH can be fabricated with a bar-coating method by applying an electric AC field between a metal bar and a substrate whose surface has transparent electrodes [15]. It seems that a uniform LC alignment can be obtained by shear flow force as well as by the effect of dielectric anisotropy.

Here, we attempted to apply the slit-coating method to fabricate ULH-LCD. It is quite beneficial that bendability and the fast response of the plastic substrate result from the simple fabrication process.

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2. Experimental

The short-pitch cholesteric LC mixture used in our experiment was originally developed by Professor Kikuchi's group for the purpose of exploring blue phase liquid crystals. The chiral dopant (2,5-bis- [4′-(hexyloxy)-phenyl-4-carbonyl]-1,4;3,6-dianhydride-D-sorbitol (ISO-$(6OBA)_2$) was synthesized and provided by Professor Kikuchi of Kyushu University. The materials were prepared in ratios of 4-cyano-4′-pentylbiphenyl (5CB, Merck): JC1041-XX (JNC Petrochemical Corp.): ISO-$(6OBA)_2$ = 46:46:8 by weight percentage. For the purpose of localizing the polymerization and forming an LC anchoring layer in the vicinity of the substrate surface, a mixture of reactive mesogen (RM)/photoinitiator mixture (UCL-011-K1, DIC Corp.) was dissolved into the cholesteric LC mixtures beforehand [16]. In order to maintain the ULH, similar to the polymer-stabilized blue phase LCD, the polymer stabilization technique has been introduced [4]. As for the substrate, a glass plate (t = 1.1 mm) or polycarbonate (PC) film (t = 0.1 mm) with transparent electrodes (Indium-Tin-Oxide film, ITO) whose rectangular electrode area is $15 \times 22\,\mathrm{mm}^2$ was used. The LC layer was formed by slit coating [11]–[14] under the following conditions: the slit-lip width was $20\,\mu$m, and the coating gap (i.e., the distance between the substrate and the lip) was approximately $100\,\mu$m. The moving velocity of the stage was 0.5 mm/s as controlled by a stepper motor. During the slit coating, UV light with a center wavelength of 365 nm and $100\,\mathrm{mW/cm^2}$ (SP-9, USHIO) was irradiated on a coated LC layer for 50 seconds, where the absorption of UV light by a PC film substrate is estimated to be approximately 40%. Simultaneously, AC electric voltage with 1 kHz, $200\,\mathrm{V_{p-p}}$ was applied to the LC layer between the ITO electrode and the slit lip. After coating an LC layer on the substrate, a small amount of glue was pasted around the margin of the substrate; we then gently laminated another PC film with ITO electrode onto the LC surface, being careful to exclude air bubbles, and a sandwich-type ULH LCD was completed.

In order to observe the electro-optic response, the cell was placed between crossed-Nicol polarizers so that the angle between the coating direction and the optical axis of the polarizer was 10°. The light transmitted (He-Ne laser, λ = 632.8 nm) through the sample cell was detected with a photo detector. The change in the transmittance was observed under the applied voltage (10 V, 4 kHz, triangular

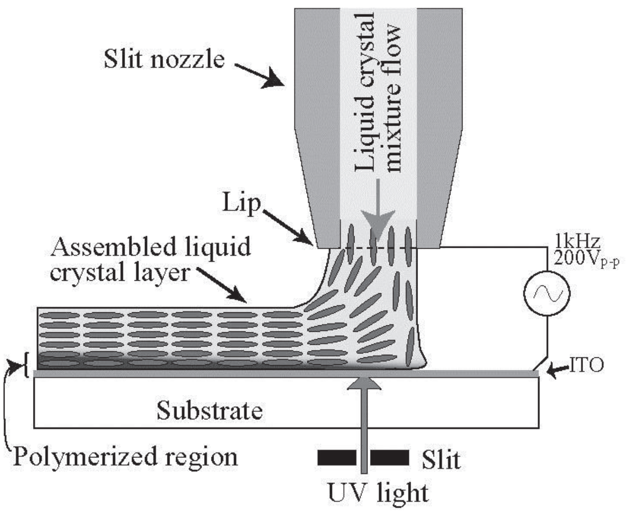


Fig. 1 Schematic model of the slit coater, where AC voltage as a stabilization of the helix was applied between the slit lips and the ITO electrode

waveform). The dynamic electrical response was also observed by applied voltages (10-30 V, 2 kHz, triangular waveform).

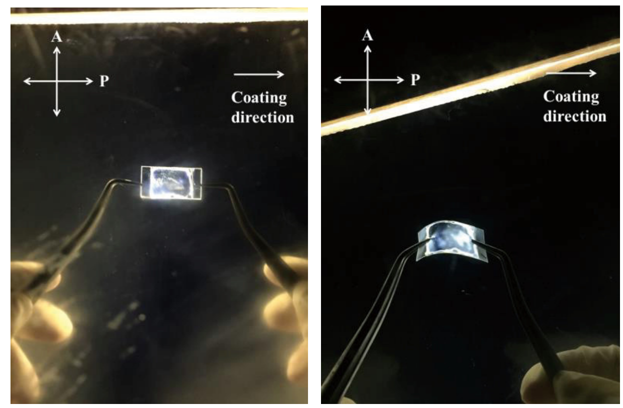
3. Results and Discussion

Figure 2 shows the appearance of the ULH LCD, where the driving area is approximately $15 \times 22\,\text{mm}^2$. Nematic LC is superior to smectic LC in robustness against mechanical stress. As shown in Fig. 2, this sample LCD made by polycarbonate film substrates was bendable. Immediately after two LC-coated substrates were sandwiched, fairly uniform alignment was confirmed. Then, during bending and when the mechanical stress was removed, the uniform texture was maintained while the cell gap was maintained.

Figure 3 shows microphotographs of the ULH texture after bending and the removal of the electric field. Fairly uniform LC alignment was found, whereas some streaks were revealed in the texture.

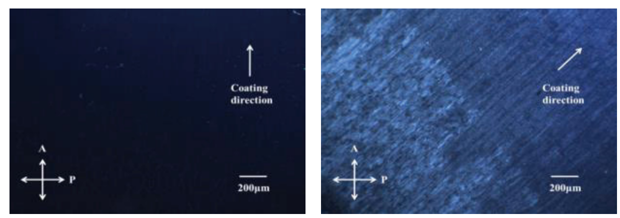
The mechanism of the helix's tendency to align perpendicularly to the slit-coating direction is interpreted as follows: as demonstrated in our previous papers [11]–[14], LC molecules tend to align parallel to the coating direction because of the shear-induced flow. As for the helix's direction, however, it is possible to form a standing helix (Grandjean texture) against the substrate. When a relatively weak electric field is applied to the cholesteric LC layer, as shown in Fig. 1, the standing helix alignment is more disadvantageous than the lying helix alignment from the viewpoint of the dielectric energy. Therefore, the helical direction turns to align perpendicularly to the slit-coating direction, as illustrated in Fig. 4.

Figure 5 represents the dependence of the induced tilt angle of the helix on the applied electric voltage, where the substrate on which the LC was coated was made of glass, and then the PC film was laminated on the LC layer. It



(a) immediately after fabrication (b) during bending

Fig. 2 Aspects of the ULH LCD where PC films were used as the substrate



(a) 0° (b) 45°

Fig. 3 Microphotographs of the ULH texture after bending and removal from the electrical field. (a) The coating direction is parallel to the analyzer. (b) The coating direction is 45° with respect to the analyzer.

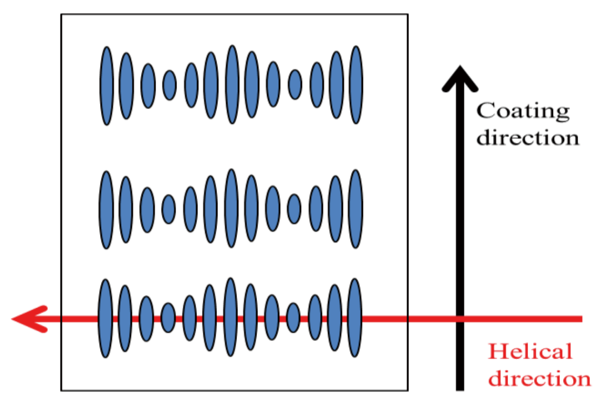


Fig. 4 Illustrated model of the slit-coating direction and the resultant helical direction

was found that the tilt angle is almost proportional to the applied voltage and exhibits a saturation tendency. As previously mentioned [3], the linear region in Fig. 6 is caused by the major contribution of the flexoelectric effect. When the voltage applied is increased above 20 V, the saturation tendency is revealed due to the helix's unwinding. For the purpose of display application, tilt angles of 22.5 degrees are sufficient [10]; therefore, the sample LC material used in our experiment is suitable for ULH LCDs.

Figure 6 represents an electro-optical response of a ULH LCD, where the sample substrate was glass, and the

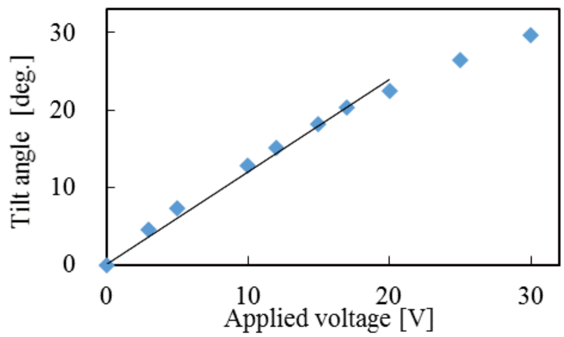


Fig. 5 Induced optical tilt angle versus the applied voltage

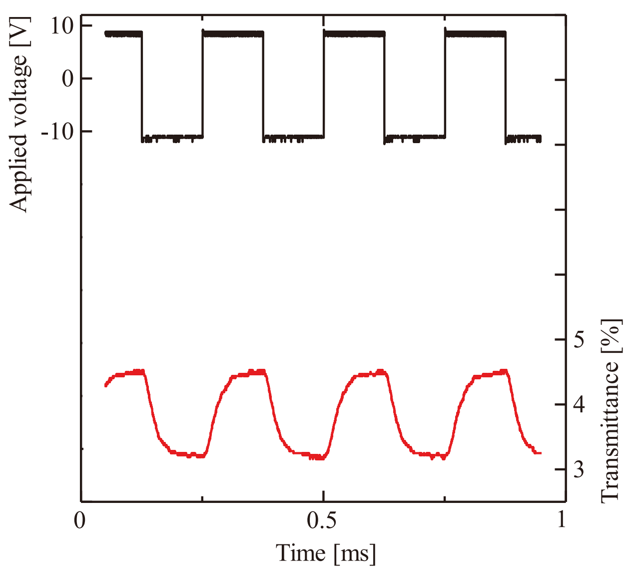


Fig. 6 Electro-optical response of the ULH LCD, where the driving rectangular voltage was 20 V_{p-p}, 4 kHz

fabrication condition was the same as that for Fig. 5. The driving rectangular voltage was 20 V_{p-p}, 4 kHz. The response time seems to be approximately 100 μs, which is substantially faster than the conventional nematic LCD mode. However, the contrast ratio is unsatisfactory because the extinction level (e.g., dark state) is poor, due to light leakage from the streaks, as found in Fig. 3 (b). To improve the contrast ratio, a more uniform LC alignment seems to be required.

4. Conclusion

We demonstrated a novel fabrication process for ULH LCDs by means of a slit coater. It is beneficial that the process is applicable to plastic substrate films because the conventional LC alignment film is not required. However, the LC alignment is still less than satisfactory, and additional improvements (choice of LC materials, slit-coating conditions) are expected.

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