Study of Liquid Crystal Alignment Using Slit Coater under Different Application Velocities

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We investigate the optimal fabrication conditions for the slit coater method, a novel manufacturing process for liquid crystal displays (LCDs). The optimal coating velocity to obtain a homogeneous LC alignment was found to be 1.0 mm/s for an LC mixture with a viscosity of around 100 mPa·s. It was also found that a periodic LC alignment pattern is formed when a high coating velocity is used, which reflects the fluid dynamic turbulence. This periodic pattern can be acquired by a UV-polymerized reactive mesogen (RM) layer that has the function of an LC alignment film.

Keywords: Flexible display, Printable electronics, Reactive mesogen, Nematic liquid crystal, Shear flow

1. Introduction

The liquid crystal display (LCD) is a representative device of the human–machine interface. At present, the fragility of display panels is an unresolved problem for the performance of LCDs that is principally due to the use of glass substrates. To maintain a stable and durable orientation of the liquid crystal (LC) molecules, an alignment layer is coated on a substrate using a thermal process, and it is this thermal process that necessitates the use of a glass substrate. If an alternative to this thermal process could be developed, the glass substrates could be replaced by plastic substrates [1]. To date, several kinds of flexible LCDs with plastic substrates have been demonstrated. Prof. Fujikake’s group has demonstrated flexible LCDs that use polymer-wall technologies [2], and bendable LCDs have been realized using polyimide substrates [3]. Recently, the slit coater method was devised as a novel fabrication process for flexible LCDs [4–9]. The advantage of the slit coater method is that an alignment film and its thermal coating process are unnecessary. Twisted nematic (TN) mode LCDs, in-plane switching (IPS) mode LCDs, and uniform lying helix (ULH) mode LCDs fabricated by the slit coater method have been demonstrated [5,9], and the surface anchoring energy has been surveyed [6,7]. However, the optimal fabrication conditions of the slit coating of LC materials has not yet been investigated.

In this work, the influences of LC coating thickness and coating velocity on LC alignment were studied using a 100-mm-width slit coater. From this study, it was found that a peculiar periodic texture is exhibited under certain conditions. We discuss whether this periodic texture arises from the bulk LC alignment or surface LC alignment through the memory effect.

2. Experimental

Figure 1 shows a schematic diagram of the slit coater system, including the slit nozzle (Toray Engineering Co. Ltd., Japan) and a light emitting diode array (λ=365 nm, PUV-60024-30CA, CCS Inc., Japan) as a UV-light source. A nematic liquid crystal (NLC, provided by Merck performance materials Ltd., Japan) and reactive mesogen (RM,
UCL-011K1, DIC co., Japan) mixture is injected into a slit nozzle through a naflon tube and coated onto a substrate, where the RM dosage into the host NLC was 1 wt%. The host NLC was a mixture of fluorinated biphenyl compounds for an active matrix drive LCD, whose viscosity was around 100 mPas. The slit width was 20 μm, the slit length was 100 mm, the gap between the slit nozzle lip and substrate was approximately 100 μm, and the coating length was 45 mm. Because of the transparency to UV light (365 nm) and surface wettability, a glass substrate (100-mm width and 1.1-mm thickness) was used in this experiment. The meniscus generation period, which is the stabilization time right after the LC bead is discharged from the slit nozzle lip and the bead approached the substrate, was 0.3 s. It is expected that the molecular order of the mixture of LC and RM is brought about by the shear flow between the slit nozzle and the substrate on the moving stage, where the moving stage is moved at a specific velocity. To polymerize the RM, UV light of 100 mW/cm² was emitted from the substrate side during the LC mixture coating.

It is assumed that different coating velocities cause different effects on the LC alignment on the substrate. Based on this assumption, a series of samples with the following coating velocities were fabricated; for a coated LC layer thickness of 2 μm, the coating velocity was 1.0, 2.0, and 3.0 mm/s, for a coated LC layer thickness of 5 μm the coating velocity was 0.3, 0.6, 0.8, 1.0, and 5.0 mm/s, respectively. (Parallel) represents a coating direction (arrow) parallel to the analyzer under crossed-nicol. (45°) represents a coating direction 45° with respect to the polarizer under crossed-nicol. In these pictures, A and P represent the optical axes of the analyzer and polarizer.
extinction state appears, whereas when the coating direction is 45° with respect to the polarizer/analyzer, the transmission state appears because of the birefringence effect. The samples were all fabricated at room temperature.

3. Results and discussion

To confirm the repeatability of the results, several samples were fabricated under identical conditions (LC layer thickness and coating velocity). However, the obtained results were not consistent: under the same fabrication conditions, each sample exhibited differences in contrast and in the pattern or director distribution, as can be shown by representative photographs for each coating condition in the extinction/transmission state. Figure 2 shows photographs of LC alignment fabricated by a slit coater for a nominal coated LC thickness of 5 μm and coating velocities of 0.3, 0.6, 0.8, 1.0, and 5.0 mm/s, respectively. Figure 2 reveals that when the stage velocity was slower than 0.8 mm/s, no satisfactory LC alignment could be obtained; the LC thickness was uneven and the LC order was not uniform. These results suggest that the induced shear force is insufficient when the stage moving velocity is slow. When the stage velocity was 5.0 mm/s, the LC alignment was streaky, indicating that unexpected LC turbulence was induced by an excessive shear force. When the stage velocity was 1.0 mm/s, a desirable LC alignment was obtained. When the coating direction with respect to the polarizer was 45°, many black spots appeared in the photos. It is likely the case that the LC was repelled by the glass substrate in these areas due to an unclean substrate. A clean substrate is very important since insufficient wettability can cause defects in the LC alignment. However, the yellowish texture caused by the LC retardation suggests that the overall LC alignment was uniform.

The thickness dependence of a coated LC on the alignment uniformity is also of interest. From the viewpoint of productivity, it is important to determine the optimum conditions for a coating velocity faster than 1 mm/s. Figure 3 shows photographs of LC alignment for a nominal coated LC thickness of 2 μm and coating velocities of 1.0, 2.0, and 3.0 mm/s, respectively. Figure 3 shows that the LC alignment is blurred when the stage velocity was faster than 2.0 mm/s. Based on this series of results, it was concluded that 1 mm/s was the optimum LC coating velocity.

Figure 4 shows microphotographs of LC
alignment for a nominal coated LC thickness of 2 μm and a coating velocity of 1.0 mm/s. As shown in Fig. 4, fairly homogeneous LC alignment is obtained under this coating condition. The order of uniformity is as good as the polymer alignment obtained using a photo-alignment technique.

Figure 5 shows microphotographs of LC alignment for a nominal coated LC thickness of 2 μm and coating velocities of 2.0 and 3.0 mm/s. It is curious that certain patterns resembling cursive script appear periodically. It is also found that the pattern cycle becomes shorter as the LC coating velocity is increased. It was assumed that this periodic pattern is caused by turbulence induced by the shear flow during the slit coating, and the increase in coating velocity makes the LC turbulent flow worse.

Another point of interest is whether the origin of this pattern is in the bulk LC or a boundary layer in the vicinity of the glass surface. The principal function of the slit coater method is to organize the LC alignment layer in the vicinity of the substrate surface. To verify this issue, a thermal cycle was applied to samples. Once the periodic structure is reproduced, even if the temperature is decreased after the temperature reaches the nematic-isotropic phase transition temperature (114°C), for a nominal coated LC thickness of 2 μm and coating velocity of 2.0 mm/s. The before-heating photo confirms that the nematic LC alignment was melted at 114°C and disappears from the periodic pattern. The periodic texture was clearly reproduced after the temperature was decreased from the nematic-isotropic phase transition temperature. This phenomenon is the same as that often seen in the surface alignment effect of a conventional polymer alignment film. In the discussions in previous papers [8,10] it has been suggested that strong UV irradiation may promote localization of polymerization near the surface [11, 12]. In other words, this result indicates that a UV-polymerized RM layer coated by a slit coater performs the same function as a conventional polymer alignment film. The following periodic structure formation process can be considered: a bead consisting of an LC and RM mixture is formed after discharging from the slit nozzle, and LC and RM molecular alignment is generated by an induced shear force by means of the moving stage [13-17]. When the stage velocity is above the optimal condition, unnecessary turbulence occurs due to the fluid dynamics, and a periodic pattern first appears.
Then, the LC and RM molecular alignment is transferred onto the glass substrate. By irradiating with UV light, localization of RM-polymerization near the surface is promoted and the polymerized layer acquires the periodic pattern of the LC alignment though a memory effect.

4. Conclusion
The influence of the LC coating thickness and coating velocity on LC alignment was studied using a slit coater. It was found that a stage velocity of 1.0 mm/s is the optimum condition for an NLC whose viscosity is around 100 mPa.s. It was also found that a periodic LC alignment pattern is formed when an excessive shear force is applied. This periodic pattern can be acquired by a UV-polymerized RM layer through a memory effect. Such a periodic alignment pattern degrades the transmittance due to light scattering and therefore slit coating of LCs should be carried out at the optimal coating condition. Further experiments, such as a study of the relationship between the LC viscosity and coating velocity, are required to further optimize the coating process, and are planned for the near future.

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References