Fabrication of Single-Substrate Flexible LCD using Nano-Phase-Separated Liquid Crystal by Coating Method

Teppei Azuma[1], Takahiro Ishinabe[1], Yosei Shibata[1], Yuichi Momoi[2], Osamu Haba[3], Hideo Fujikake[1]

e-mail: teppei.azuma.q2@dc.tohoku.ac.jp
[1]Tohoku University, 6-6-05 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
[2]Toyo Co.,Ltd. 13-4 Kamitanabe, Takatsuki,Osaka 569-0805,Japan
[3]Yamagata University 4-3-16 Jonan,Yonezawa,Yamagata 992-8510, Japan
Keywords: Liquid crystal display, Flexible display, Single substrate, Polymer spacer, Coating method

ABSTRACT

We have developed the single-substrate LCD to realize flexible LCDs with both high flexibility and high image quality. By using NPS-LCs, liquid crystalline dendrimers, and stretchable cover film, we successfully achieved LC layers with high uniform LC alignment by coating method.

1. Introduction

Flexible liquid crystal displays (LCDs) using plastic substrates are expected to be applied to various applications such as automobile displays, roll screen televisions, and wearable devices because of their high reliability at high temperatures as well as excellent shock resistance.

The structure of conventional flexible LCDs consists of two plastic substrates fixed at both ends with sealing material. In this case, since each substrate has a neutral plane, the amount of distortion of the substrate above and below the LC layer becomes different during curvature due to the difference in the radius of curvature [1].

As a result, a compressive force is exerted at the center of the LC cell and an expansion force is exerted at the edge of the substrate, causing a change in the thickness of the liquid crystal layer and a change in the LC alignment direction due to a flow of LCs (Fig. 1a). This has been a problem because it reduces the brightness and contrast ratio of the display devices.

To solve these problems, we have proposed bonding polymer spacers formed in LCs, and have shown that bonding the top and bottom substrates creates a single neutral plane and suppresses a change in the thickness of the LC layer [2]. However, there was still the problem that flexibility was limited dur to the use of two substrates.

In this paper, we have investigated the fabrication of LCDs using single-substrate. Because there is only one substrate, the flexibility of LCDs can be improved. In addition, because there is only one neutral plane, the LC layer is not affected by changes in thickness or flow of LCs due to curvature, and high image quality can be expected during curvature.

Here, a protection layer for LCs is necessary in single-substrate LCDs. Therefore, we used the stretchable films as a protection layer. Elongation of the protection layer during curvature allows the neutral surface of LCDs to remain one (Fig. 1b). The polarizer was also made of stretchable material so that the neutral surface would be one.

In this paper, we investigated the fabrication of flexible single-substrate LCDs with both high flexibility and high image quality by using coating method.

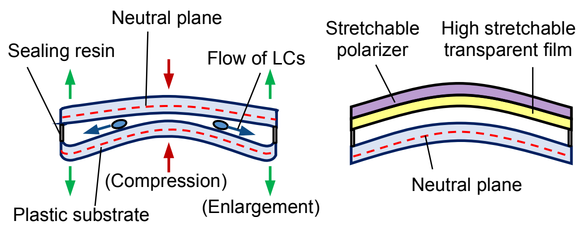


Fig. 1 Neutral plane of flexible LCDs in a curved state.

2. Structure of the Proposed Single-Substrate LCDs

The structure of the single-substrate LCDs proposed in this study is shown in Fig. 2.

We used Nano-phase-separated (NPS) LCs (DIC corp.) as the LC layer. NPS LCs form nano-sized polymer networks in the LCs by UV irradiation. As a result, we can achieve a contrast ratio while suppressing a flow of LCs during curvature [2].

In this study, the LC layer was formed by coating method to simplify the fabrication. To create single-substrate LCDs with highly uniform LC alignment, it is necessary to achieve vertical LC alignment by coating method. However, in general, the hydrophobic structure in the alignment film makes it difficult to coat LCs on a vertical alignment film.

Therefore, we focused on liquid crystalline dendrimers with mesogenic groups in their side chains as a method of LC aligning without using alignment films. This material has the property of spontaneously forming a monolayer on the surface of the substrate. When added to LCs, it has the function of vertically aligning LCs. This material is thought to enable vertical alignment of liquid crystals by coating method [3].

A high stretchable transparent film was also used over the LC layer as the protection layer. The protection layer elongates to follow the curvature of the substrate, which is thought to keep the thickness of the LC layer constant and suppress the degradation of image quality.

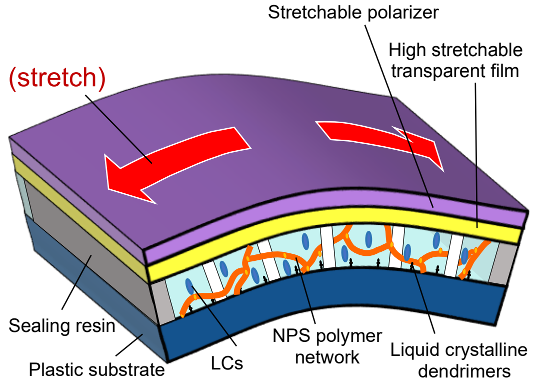
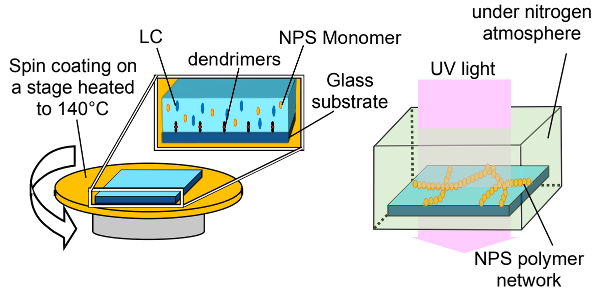


Fig. 2 Structure of the proposed single-substrate LCDs.

3. Formation of LC Layer by Coating Method

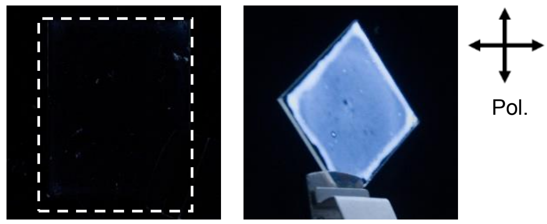
We used glass substrate to establish a fabrication condition of single-substrate LCDs. The fabrication procedure of the LC layer is shown below. 0.5 wt% of polymerization initiator and 0.1 wt% of liquid crystalline dendrimers (D2-6PC5) with mesogenic groups on the side chain were added to NPS-LC (NA-1220NPS, DIC) containing monomer. Next, the mixed solution was coated on a glass substrate with a post spacer fabricated using photolithography technology. Hight of the post spacer was 3 μm. Comb electrodes with a pitch of 10 μm were used on a glass substrate.

First, substrates were subjected to UV cleaning (AOBA SCIENCE L-204) for 30 min. and then the mixture was dropped onto the substrates on a stage heated to 140°C, where the mixture showed an isotropic phase, followed by spin coating at a rotation speed of 1250 rpm and the time of 30 sec. to form the LC layer with a thickness of 3 μm (Fig. 3a). The polymer network was formed by irradiating the entire substrate with UV light using a collimated UV light source (JATEC) with a wavelength of 365 nm under room temperature and nitrogen atmosphere (Fig. 3b). The integrated UV intensity was set at 12 J/cm^2. The prototype liquid crystal layer is observed under an orthogonal polarizer (Fig. 4).



(a) LC layer coating (b) UV irradiation

Fig. 3 Fabrication process using dendrimer.



(a) Fabricated LC layer observed in normal direction (b) Observation at 45° to the polarizer

Fig. 4 Vertically aligned NPS-LC layer formed by coating method on a glass substrate.

To evaluate the alignment distribution of the LC layer, we measured the angle (polar angle) - retardation characteristics by using a spectroscopic ellipsometer (M-2000, J. A. Woolam) (Fig. 5). By fitting the results, it was confirmed that a vertically aligned LC layer with a pretilt angle of 90° could be realized by the coating method using the dendrimer.

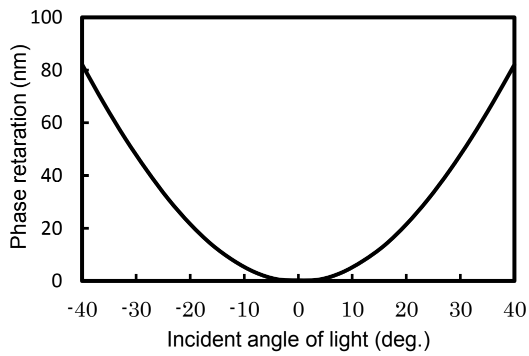


Fig. 5 Incident angle - retardation characteristics of the liquid crystal layer.

Next, the voltage-transmittance characteristics were measured using a polarizing microscope (BH-2, Olympus) to evaluate the electro-optical properties of the LC layer (Fig. 6). It can be seen that the vertically aligned LC molecules are tilted by the application of voltage, resulting in an increase in transmittance (Fig. 7).

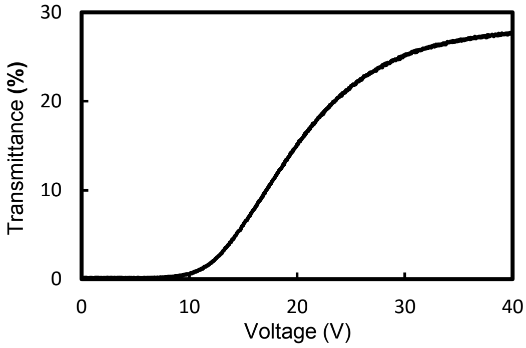


Fig. 6 Voltage-transmittance characteristics of the fabricated LC layer.

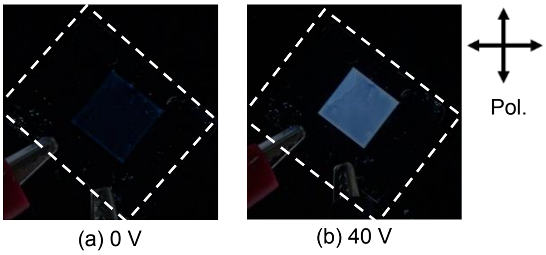


Fig. 7 Voltage drive of vertically aligned NPS-LC layer formed by coating method.

4. Formation of Protection Layer using High Stretchable Transparent Film

Next, we examined the fabrication of the protection layer. As the protection layer, an acrylic cross-linked film (Suave-10F60, Osaka Organic Chemical Industry Ltd.) with a thickness of 60 μm was laminated. This film has higher adhesiveness than silicon and superior heat and humidity resistance compared to urethane (Fig. 8).

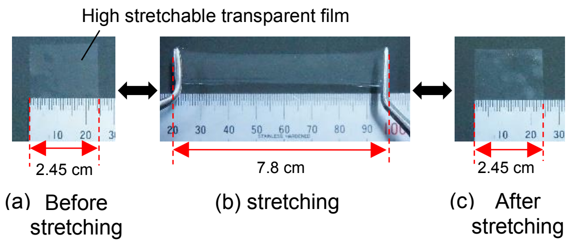


Fig. 8 Before and after stretching of High stretchable transparent film.

A stretchable film laminated with a stretchable polarizer was placed on top of the liquid crystal layer and observed under the Crossed-Nicol polarizers (Fig. 9).

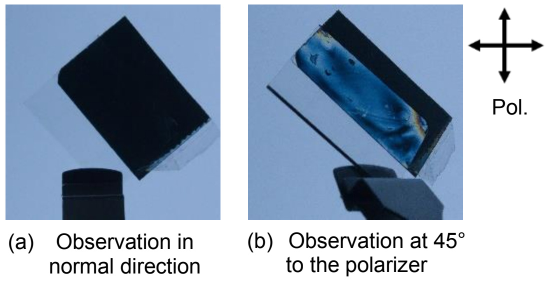


Fig. 9 Lamination of UV-cleaned stretchable film.

From Fig. 9a, we confirmed that the transmittance is low under the crossed polarizers and vertically aligned LCs are achieved across the entire substrate. On the other hand, when observed from an angle, the transmittance increases due to the birefringence of the LCs, however, we found that the transmittance is less uniform (Fig. 9b). This was thought to be caused by a partial change in the thickness of the LC layer. The change in the thickness of the LC layer was caused by the wettability of the surface of the stretchable film, therefore we examined the substrate cleaning conditions. Plasma cleaning was newly applied to the prototype, and Fig. 10 shows a comparison of the samples.

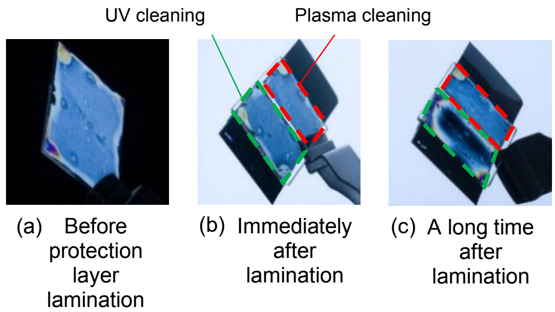
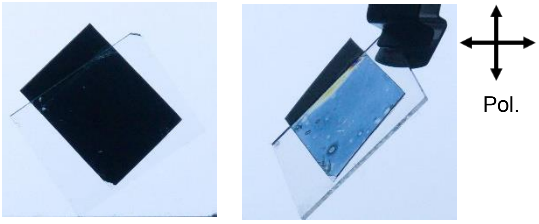


Fig. 10 Comparison of cleaning methods for stretchable films.

Although immediately after the lamination of the stretchable film, a uniform LC layer thickness was observed in both cases. However, only the UV-cleaned area was found to become dark in the center over time, while the edges showed interference colors due to birefringence. The cause of this phenomenon is thought to be that the LCs in the center moves to the edge and the phase retardation changes due to the change in the LC layer thickness. On the other hand, the plasma-cleaned area showed highly uniform LC alignment after lamination. From the above results, we confirmed that by using the plasma-cleaned stretchable film, the surface wettability was improved and the protection layer could be formed without affecting the LC layer (Fig. 11).



(a) Observation in normal direction (b) Observation at 45° to the polarizer

Fig. 11 Single-substrate LCD using plasma-cleaned stretchable film and stretchable polarizer.

To evaluate the electro-optical properties of the LC layer after the laminating of the protection layer, the voltage-transmittance characteristics were measured (Fig. 12). From these results, we confirmed that light modulation was generated by the application of voltage as before the formation of the protection layer.

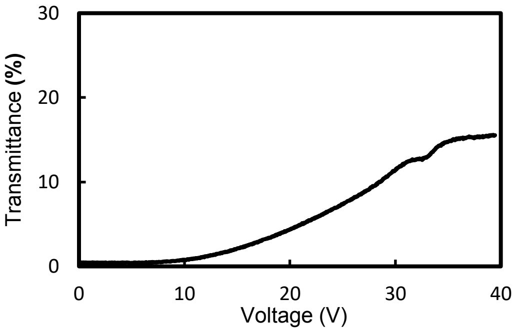


Fig. 12 Voltage-transmittance characteristics of single-substrate LCDs with the protection layer.

5. Conclusions

To realize flexible LCDs with both high flexibility and high image quality, we proposed single-substrate LCDs using vertically aligned NPS-LC layers by LC coating method and a stretchable transparent film as a protection layer. The results show that it is possible to form the LC layer with high uniform LC alignment by coating method using liquid crystalline dendrimers. It was also found that laminating the stretchable film with plasma cleaning treatment improved the wettability of the protection layer surface and retained the liquid crystal layer after the protection layer was formed. We also confirmed that the prototype device is capable of optical modulation by the applied voltage.

In the future, we plan to make a prototype of single-substrate LCDs using a plastic substrate instead of a glass substrate and evaluate its curvature performance.

References

[1] H. F. Shuichi Honda, Takahiro Ishinabe, Shogo Takashi, Yohei Shibata, "Analysis on Bending Deformation of Plastic Substrates of Flexible LiquidCristal Displays," *J. Inst. Image Inf. Telev. Eng.*, vol. 72, pp. 131–135, 2018.

[2] F. Toru *et al.*, "Properties of nano-phase-separated LCs with fast response," *Proc. Int. Disp. Work.*, vol. 1, pp. 366–369, 2015.

[3] Y. Momoi *et al.*, "Polyimide - free LCD by dissolving dendrimers," *J. Soc. Inf. Disp.*, vol. 20, no. 9, pp. 486–492, 2012.