Microscopic Polymer Structure Formation of PDLCs by Patterned UV Irradiation for Viewing Angle Controllable LCDs

Sou Matsuoka, Takahiro Ishinabe, Yosei Shibata, Hideo Fujikake

Tohoku University, 6-6-05 Aoba, Aramaki, Aoba-ku, Sendai 980-8579, Japan
Keywords: Polymer-dispersed liquid crystal, Polymer structure, Light control, UV-curing

ABSTRACT

We established a control technique of the polymer aggregation structure in PDLCs by the pattern UV exposure using a photomask to control the diffused light distribution of PDLCs. As a result, we clarified that successfully achieved a precise control of the fine polymer aggregation structure by used the polymerization inhibitor.

1. INTRODUCTION

To improve the functionality and light utilization efficiency of electronic displays and illumination devices, it has become important to develop methods to control the light distribution pattern. Polymer-dispersed liquid crystals (PDLCs) have been widely utilized to control light diffusion according to the difference in refractive index between the liquid crystal and polymer network [1, 2]. However, when PDLCs are fabricated by using a diffused ultraviolet (UV) light source, a random polymer network structure is formed and the incident light is diffused isotropically, making it difficult to precisely control the distribution pattern of diffused light. Therefore, it is necessary to establish a technique for controlling the polymer structure in the PDLCs to control the light diffusion distribution.

We have previously reported the fabrication of a layered polymer aggregation structure in PDLCs by using anisotropically diffused UV light (Fig. 1). By controlling the directivity of UV light, the polymer aggregation structure can be controlled two-dimensionally and allowing control of the diffused light distribution according to the polymer structure [3, 4].

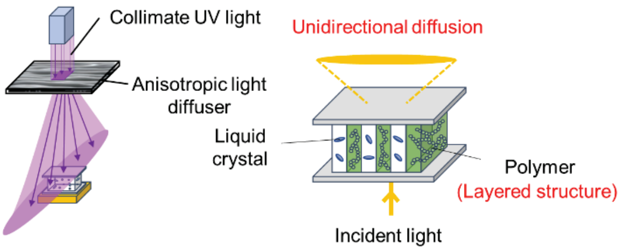


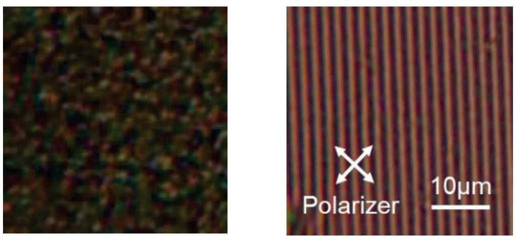
Fig. 1 Fabrication of layer-structured PDLC by using directional UV light.

However, it is difficult to achieve distribution control in a two-dimensional plane by using this technique with anisotropically diffused UV light, because UV light is evenly applied to the liquid crystal element. In this paper, we investigated the fabrication of PDLCs with a controlled fine polymer aggregation structure by using a photomask to control the two-dimensional distribution of UV light.

2. FABRICATION CONDITION OF PDLCS

We have previously reported the control of polymer aggregation structure by using photomasks for flexible LCDs [5, 6]. The width of the polymer spacer was 10 μm and the pitch was 100 μm. However, to use the polymer aggregates as a light distribution control element, a polymer aggregation structures with a pitch of several micrometers are required.

When UV exposure was performed using a photomask with a pitch of several micrometers, the polymer aggregate structure was randomly formed as shown in Fig. 2(a), and control of the diffused light distribution was difficult. As this factor, the UV light passing through a photomask with a pitch of several micrometers is diffracted due to the fine mask pattern while irradiating the LC mixture. Therefore, it is necessary to reduce the substrate and cell thickness to suppress the influence of UV diffraction. In addition, when UV irradiation is performed at room temperature, the LC mixture exhibited a nematic phase and becomes scattered, so that the structure controlled PDLC could not be obtained since the UV light transmitted through the photomask was disturbed. Therefore, by controlling the temperature of the mixture to an isotropic phase, the ultraviolet rays are irradiated without being scattered, so that a polymer aggregate structure along the mask pattern is formed. From the above, we achieved the striped polymer aggregate structure with a 2 μm pitch as shown in Fig. 2(b) by using thin polyethylene terephthalate (PET) substrates with thickness of 50 μm, and thin PDLC film of 5 μm, and irradiating the sample with UV light at a temperature of at 50°C in which the LC mixture becomes an isotropic phase.



(a) Random polymer structure **(b) Striped polymer structure**

Fig. 2 Polymer aggregation structure of PDLCs fabricated using photomask.

However, when UV irradiation is performed using a fine photomask with a wide exposure area, the monomer concentration increased and the influence of UV light diffraction on the light-shielding portion also increased.

For this reason, to form a fine polymer aggregation structure corresponding to the mask pattern, suppression of polymer dispersion to the light-shielding portion is required.

In this paper, we investigated the effects of the addition of a polymerization inhibitor on phase separation of monomer in the liquid crystal mixture by evaluating the polymer structure of the fabricated PDLCs.

3. EXPERIMENT

We fabricated the PDLCs as the following procedure. Nematic liquid crystal E-7 (phase transition temperature: 59.8 °C, Merck) and liquid crystalline monomer (DIC) having the polymerization inhibitor were mixed at a weight ratio of 1:1. We used the liquid crystalline monomer to control the alignment of liquid crystals and polymers in the microscopic region. The mixed solution was injected into the empty cell composed of two polyethylene terephthalate (PET) substrates without alignment treatment. The thickness of the PET substrate was 50 μm. A photomask in which the exposure regions are formed in a lattice pattern was placed on the cell, as shown in Fig. 3. The width of exposure region was 2 μm and the pitch was 7 μm. A polymer structure was formed by UV irradiation using a collimated UV light source (JATEC) with a wavelength of 365 nm while controlling the temperature at 50°C with a hot plate. The UV illuminance was 2 mW/cm^2, and the irradiation time was 3,000 s. After UV irradiation using a photomask, the second UV irradiation was performed to the whole area with UV illuminance of 20 mW/cm^2 and irradiation time of 600 s.

The polymer aggregate structure of the fabricated PDLC was examined by using a polarizing microscope under a crossed Nicol condition, where the one side substrate was peeled off and the liquid crystal was removed by the ethanol (Fig. 4).

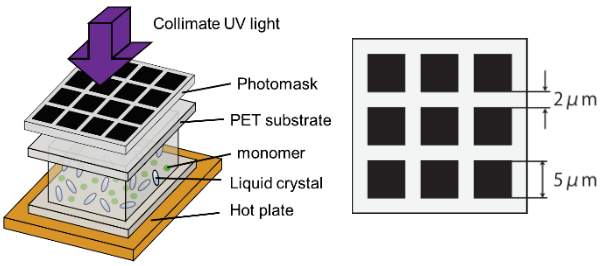


Fig. 3 Fabrication process of PDLCs using patterned UV irradiation.

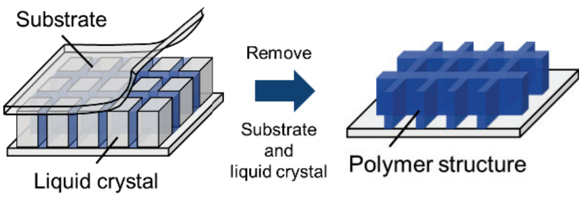


Fig. 4 Observation method of polymer structure.

4. RESULTS AND DISCUSSION

Figure 5 shows an observation image of the exposure surface of the PDLC fabricated using monomer material without a polymerization inhibitor. As shown in Fig. 5, we confirmed the polymer was formed in a lattice shape, however, a polymer aggregate structure was also precipitated in the masked region. The width of the polymer aggregate structure was wider than the exposure region (2.0 μm) of the photomask.

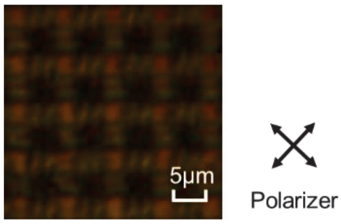


Fig. 5 Observation result of polymer structure in PDLCs without polymerization inhibitor.

Figure 6 shows an observation result of the exposure surface of a PDLC fabricated using monomer material with a polymerization inhibitor. As shown in Fig. 6, the polymer was formed in a lattice shape. Compared to the case without the addition of polymerization inhibitor, precipitation of the polymer in the liquid crystal region was suppressed, and the lattice width of the polymer aggregation structure was about 2.0 μm.

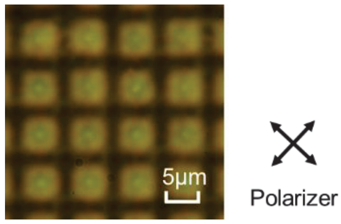
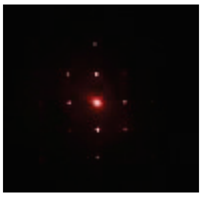
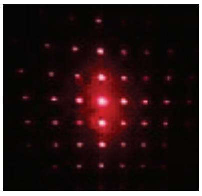


Fig. 6 Observation result of polymer structure in PDLC using polymerization inhibitor.

Figure 7 shows the state of diffused light when laser light is incident on the fabricated PDLCs. As shown in Fig. 7, the light was diffused over a wider range in the case of PDLC cell fabricated using the polymerization inhibitor. Based on the above results, in polymer structure control of PDLC by two-dimensional control of UV irradiation distribution using a photomask, we clarified the addition of a polymerization inhibitor suppressed polymer diffusion, and it was effective for fine control of the polymer structure.



(a) PDLC without Polymerization inhibitor



(b) PDLC with Polymerization inhibitor

Fig. 7 Light diffusion pattern by PDLCs.

5. CONCLUSION

We have investigated a control technique of the polymer aggregation structure in PDLCs by the pattern UV exposure using a photomask to control the diffused light distribution of PDLCs. As a result, we clarified that the addition of a polymerization inhibitor suppressed polymer diffusion in the masked area, and successfully achieved a precise control of the fine polymer aggregation structure in PDLCs.

REFERENCES

[1] J. Y. Kim & P. Palffy-muhoray "Phase Separation Kinetics of a Liquid Crystal- Polymer Mixture" Molecular Crystals and Liquid Crystals, 203, pp. 93-100 (1991)

[2] Y. Hisatake, Y. Kawata, and A. Murayama, "31 . 3 : Viewing Angle Controllable LCD using Variable Optical Compensator and Variable Diffuser Cell Structure", SID 05 DIGEST, pp. 1218–1221 (2005).

[3] Y. Horii, Y.Shibata, T.Ishinabe, and H.Hideo, "Formation of Layered Polymer Structure of PDLC by Anisotropically Diffused UV irradiation" IDW' 17, pp. 305-307 (2017)

[4] Y. Horii, Y.Shibata, T.Ishinabe, and H.Hideo, "Evaluation of Polymer Structure Distribution in PDLC Fabricated by Directional UV Irradiation" Proceeding of the Japanese Liquid Crystal Conference, PB41, (2018)

[5] H.Sato, H.Fujikake, Y.Iino, M.Kawakita and H.Kikuchi, "Flexible Grayscale Ferroelectric Liquid Crystal Device Containing Polymer Walls and Networks," J.J.Appl.Phys., vol.41, pp.5302-5306, (2002)

[6] H.Sakai, T.Ishinabe, H.Fujikake, "Driving Voltage Reduction of Flexible Blue Phase Liquid Crystal Devices Containing Polymer Walls," Proc.IDW, pp.159-160, (2015)