

P-99: Fabrication of Dual-Domain Twisted Structure in Polymer and Liquid Crystal Composite Systems

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Abstract

We have fabricated dual-domain twisted structure by imprinting of LC alignment on polymer layers during polymerizing induced phase separation in polymer and liquid crystal (LC) composite systems. By application of electric field during UV exposure, the photopolymerized polymer chains are formed along the long molecular axis of LC aligned by the field. The aligned polymer chains align LC molecules after removing the field. Using this method, we successfully fabricated dual-domain twisted nematic structures.

1. Introduction

Recently, various methods have been developed to improve viewing characteristics of liquid crystal displays (LCDs). For example, compensation films method [1,2], multi domain twisted nematic (TN) mode [3,4], multi-domain vertical alignment (VA) [5] and inplane switching (IPS) mode [6], and optically compensated bend (OCB) mode [7] were proposed and demonstrated. Among them, multi-domain technique proved to be very efficient in improving viewing angle of nematic LCDs [8]. To obtain a LCD device having more than two different LC aligning in a unit region, it is necessary to a proper alignment treatment such as multiple rubbing and polarized UV exposure. However, the methods were cumbersome due to multi-photolithographic process.

In this work, we developed a new method to prepare dual-domain twisted structure by imprinting of LC alignment on polymer

layers during anisotropic polymerization induced phase separation from polymer and nematic LC composite systems.

2. Experimental

Cells were made using two glass substrates. One of the substrates has in-plane electrode which is prepared by etching onto indium-tin-oxide (ITO) coated glass. The ITO glass substrate was spin coated with 1 wt. % of a Nylon 6 in trichloroethanol. The Nylon 6 film was rubbed after drying to achieve homogeneous LC alignment and induce anisotropic phase separation during UV exposure. The other substrate has no electrode and alignment layer. The cell gap was maintained using 5 μm glass spacers.

The materials used are E48 (Merck) for nematic LC and UV curable epoxy NOA-65 (Norland) for prepolymer. The prepolymer and the LC are mixed the ratio 50:50 and introduced in to the cell by capillary action at 100 °C which is corresponding to isotropic temperature of LC.

Phase separation is initiated by exposing the cell to UV light through the substrate without the Nylon 6 alignment layer. The source of UV light was a high pressure mercury vapor lamp operated at 400 W of electrical power. For the comparison two kinds of samples were made using different conditions as follows:

Sample I : UV exposure for 30 min. at 100 °C without bias field.

Sample II : 1st UV exposure for 10 min. at 100 °C without bias field \rightarrow 2nd UV exposure for 30 min. at 40 °C with bias field.

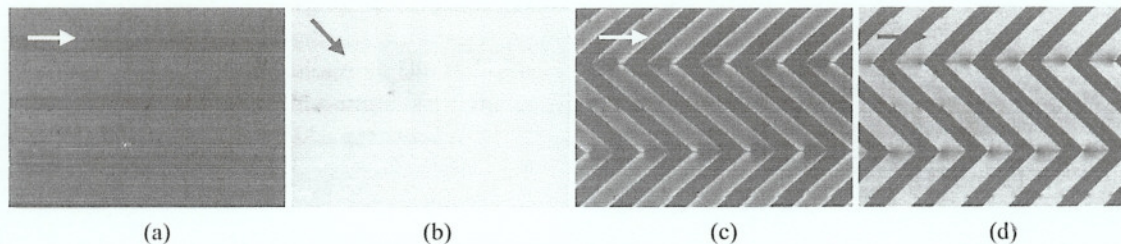


Fig. 1 Alignment textures of Sample I under polarizing microscope. Without field, uniform (a) dark and (b) white state can be obtained. (c) and (d) are the textures with electric field of 0.5 V/ μm and 1 V/ μm , respectively. The arrow indicates rubbing direction.

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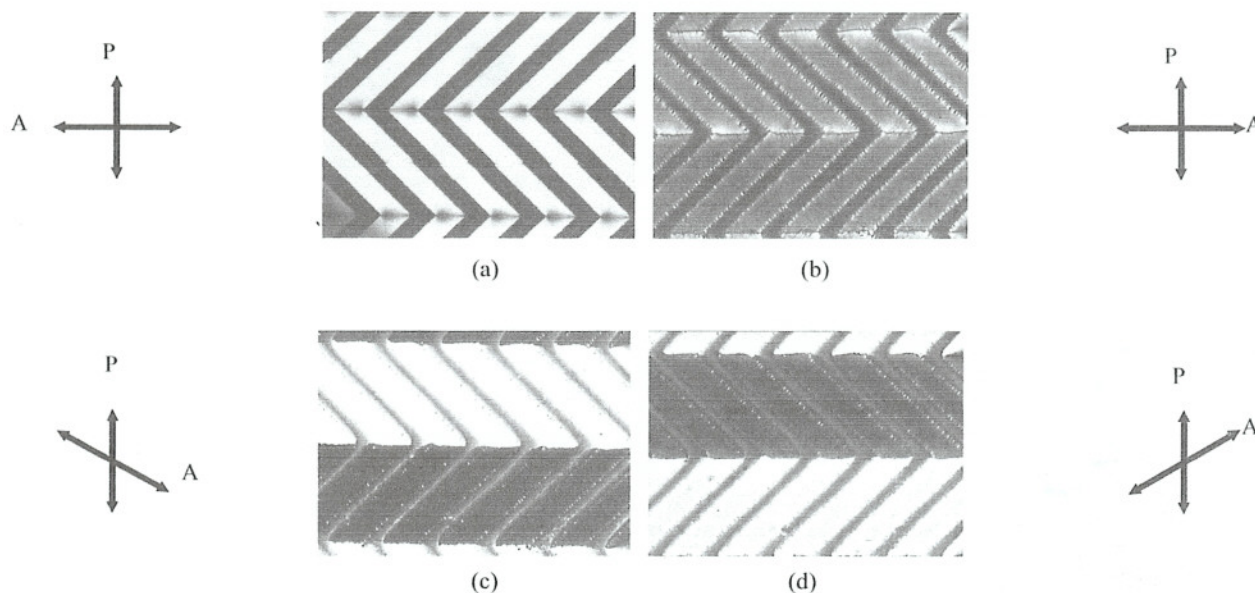


Fig. 2 Optical microphotographs of the cell before and after the second UV exposure. (a) Alignment texture with $2 \text{ V}/\mu\text{m}$ before the second UV exposure. (b)-(d) Alignment textures without field after the second UV exposure with different geometry of analyzer. The P and A represent polarizer and analyzer, respectively.

The bias field was 1 KHz square wave of 200 V.

3. Results and Discussion

Fig. 1 shows optical micrographs of Sample I with/without switching field between crossed polarizers. Without field, the uniform dark and white states are achieved due to good alignment of LC [Fig. 1 (a) and (b)]. It means that the adjacent, uniform, and parallel layers of the LC and the polymer, namely phase separated composite organic film (PSCOF), are formed between two glass substrates [9]. The mechanism responsible for the formation of PSCOF is the anisotropic polymerization due to UV intensity gradient in the cell and surface wetting properties. Above certain strength of field, the LC molecules start to reorient and align along the electric field due to their positive dielectric anisotropy of LC molecules [Fig. 1(c)]. With high field ($>1 \text{ V}/\mu\text{m}$), one can obtain white state which means that the LC molecules fully rotated 45° with respect to the rubbing direction [Fig. 1(d)]. The results demonstrate that devices are uniform and possess gray scale capability.

In order to study the effect of bias field during the phase separation, we made a cell using two-step UV exposure as we mentioned in experimental section. After the first UV exposure for 10 minutes at 100°C without bias field, we observed textures and response times at room temperature. The textures are the almost same as those of Sample I as we expected. The field driven times are about 8 ms in both samples. The relaxation times, however, are about 30 ms for the 30 minutes cured sample (Sample I) and 80 ms for the 10 minutes cured sample. Such a slower relaxation in the less cured sample is due to uncured prepolymers in LCs. It is found that it requires at least 30 minutes of UV exposure for full

cure in our system. After measurements, we set the temperature of the less cured sample at 40°C and exposed to UV for 30 minutes with a bias field of 200 V. Fig. 2 is optical micrographs of the cell before and after the second UV exposure. Fig. 2(a) is the texture with bias field before the second UV exposure at 40°C . It is quite clear the LC molecules rotated 45° with respect to the rubbing direction. After the second UV exposure, the bias field was removed and the sample was cooled down to room temperature. The relaxation time is drop to 32.5 ms which is comparable to Sample I. It means that the uncured prepolymer in LCs are fully cured by the second UV exposure. The UV exposure with bias field resulted in a significant change of LC alignment. The LC molecules segregated into the inter-electrodes as shown in Fig. 2(b). And the remaining prepolymer in the first UV exposure segregated onto the electrodes. It is known that the segregation of liquid crystals results from Kelvin type force due to a larger dielectric constant of LC than that of the prepolymer. Moreover the texture between crossed polarizers without field did not show dark state different from that of Sample I [see Fig. 1(a)]. Fig. 2(c) and (d) show alignment textures when the analyzer is rotated ± 20 degrees, respectively. It is clear that each half of the chevron has dark state with different analyzer geometry. It means that the alignment of LC molecules is twisted between glass and polymer layer in these regions as shown in Fig. 3.

The mechanism responsible for the twisted structure is probably due to the imprinting of LC alignment on polymer layers during polymerization process. By applying bias field before the second UV exposure, the long axis of LC molecules is aligned along the electric field except near alignment layer [Fig. 3(a)]. The second UV exposure stimulated the polymerization of uncured prepolymers which remain after the first UV exposure. In this

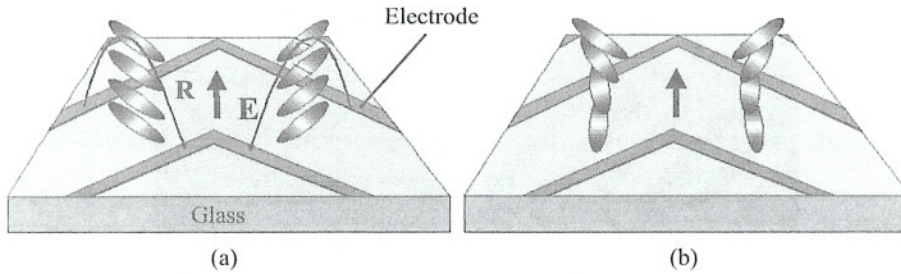


Fig. 3 Schematic diagrams of liquid crystal alignment (a) with and (b) without electric field. In the figure, R indicates the rubbing direction. The LC layer is formed between glass substrate and polymer layer which is not presented in this figure.

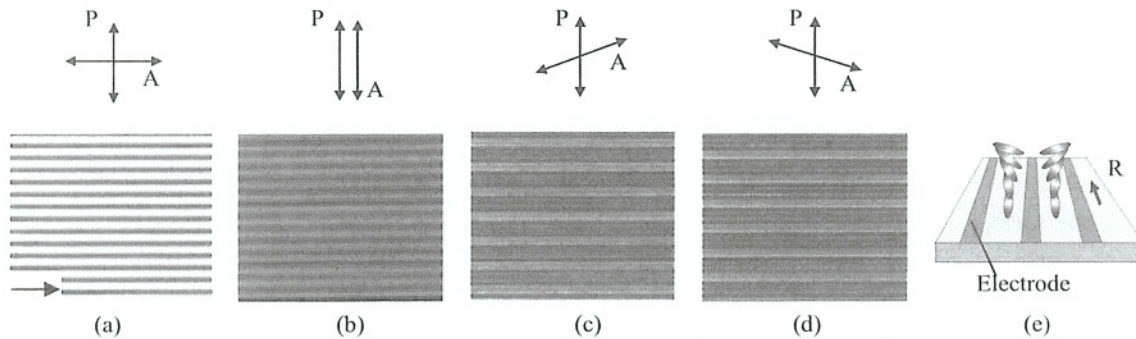


Fig. 4 Alignment textures of sample with striped IPS electrode. The angle between polarizer and analyzer is (a) 90° , (b) 0° , (c) 75° and (d) -75° . In the figure, P and A indicate polarizer and analyzer, respectively. (e) is the schematic diagram of LC alignment in the cell. Upper glass and polymer layer are not presented in this figure. The arrow indicates rubbing direction.

process, the polymer chain is formed in the direction of long axis of LC molecules to minimize elastic energy. This is somewhat analogous to the rubbing process which in the most common method to align LC. In general, the rubbing process shears the polymer chains and aligns the chains along the rubbing direction. In our case the aligned LC molecules by the electric field do the same role as a rubbing does. After full curing and removing bias field, the LC molecules near polymer layers are aligned in the direction of polymer chains [Fig. 3(b)]. However, the LC

molecules near bottom substrate are aligned along rubbing direction. As a result, we can obtain dual-domain twisted structure between polymer layer and glass substrate.

With striped IPS electrode, we can easily fabricate dual-domain TN structure using the same two-step UV exposure with bias field as shown in Fig. 4. It is note that the twist angle can be controlled depending on the strength of bias field, the exposure time of the initial UV exposure, polymerization temperature for the second UV exposure, sample thickness, and concentration of polymers.

Fig. 5 shows transmittance of dual-domain TN cell as a function of voltages in normally white and black mode.

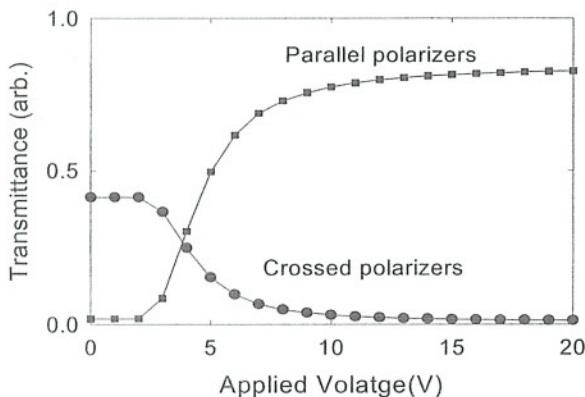


Fig. 5 Transmittance as a function of applied voltages with different geometry of the polarizers.

4. Concluding Remarks

In conclusion, we have fabricated dual-domain twisted structure by imprinting of LC alignment on polymer layers during polymerization process. This new method may open new areas for LCDs with wide viewing angle.

6. Acknowledgements

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7. References

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