Imprinting of Liquid Crystal Alignment on Polymer Layers

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We have investigated electric field effect on the formation of phase separated composite organic film structure which is utilized by anisotropic phase separation from LC and prepolymer mixtures. Application of bias field resulted in a significant change in liquid crystal alignment between glass substrate and polymer layer. The liquid crystal molecules segregated into the inter-electrodes and formed twisted structure which is the result of imprinting of LC alignment by the bias field on polymer layers during polymerization process.

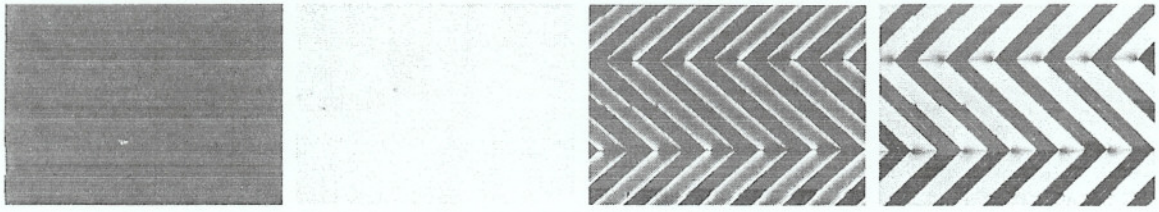
1. Introduction

The formation of highly oriented liquid crystals (LCs) is of great importance for a basic understanding of interfacial phenomena as well as device applications of LCs. A properly treated solid interface can be used effectively to align LCs in their mesophase.

It has been known for a long time that rubbing, Langmuir-Blodgett (LB) film, dielectric material oblique evaporation, ultraviolet (UV) light exposure, and other method which produce a grooved surface, can induce a uniform alignment of LCs. Among them, the rubbing method is the most common method used in commercial mass production. It is believed that the rubbing process generate elongated polymer chains by shear force.

In the past 20 years, liquid crystal (LC) and polymer composite systems have been a great interest as a new class of electro-optic (EO) structures from a fundamental as well as a practical point of view. [1-6] Most of devices using the composite systems have been utilized by photoinitiated polymerization-induced phase separation by UV exposure.[1] The resulting structure depends on a number of parameters including polymer concentration, temperature of phase separation, rate of polymerization, surface wetting properties, and so on. Most commonly, polymer dispersed liquid crystal (PDLC) structures are a result of isotropic and relatively fast phase separation at concentrations above 10 wt% of polymer. Since PDLCs operated in scattering mode and LC are confined in polymer networks, the EO properties such as contrast ratio, response time, and operating voltage are not suitable for common display applications.

Recently anisotropic phase separation method using low rate of phase separation and surface wetting properties has been developed to fabricate phase separated composite film (PSCOF) of LC and polymer[6]. In the simplest case, PSCOF method yields adjacent uniform layers of the LC and polymer parallel to glass substrate. The configuration of the optic axis in the layer can be controlled with an alignment layer on the substrate that is in contact with the LC film. Evidently, these devices operate in the birefringence mode just like the conventional pure LC devices. With only one alignment layer, twisted nematic or super twisted nematic structures have been fabricated in PSCOF structure by imprinting of LC alignment to the solidified polymers during polymerization induced anisotropic phase separation[7]. Since the direction of LC molecules at LC-polymer interface, however, is solely controlled by the twisting power of chiral dopant and sample thickness, it needs sophisticated



(a) (b) (c) (d)

Fig. 1 Without applying field, (a) and (b) are the alignment textures when the rubbing direction is (a) parallel and (b) rotated 45° with respect to the optic axis of analyzer. (c) and (d) are the textures with electric field of 0.5 V/μm and 1 V/μm, respectively. In (c) and (d), the rubbing direction is parallel to the analyzer.

process to fabricate a device with desired twist. Therefore, it is required more convenient method for mass production.

Here, we report the electric field effect on the formation of twisted structure in PSCOF.

2. Experimental

Cells were made using two glass substrates. One of the substrates has in-plane electrode which is prepared by etching 100 μm wide interdigitated electrodes onto indium-tin-oxide (ITO) coated glass with a separation of 100 μm. In order to achieve wide viewing angle, we patterned ITO in chevron shape. The ITO glass substrate was spin coated with 1 wt. % of a Nylon 6 in trichloroethanol. The Nylon 6 film was rubbed in the direction of 45 degree with respect to the electrodes 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 a temperature at 100 °C.

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 kinds of samples were made using different conditions. The first one (sample I) was exposed to UV for 30 minutes at 100 °C without bias field. The second one (sample II) was exposed to UV for approximately 10 minutes at 100 °C without bias field. After following the initial UV exposure, the cell was cooled down to 40 °C and then exposed to UV for 30 minutes with bias filed. The bias field was 1 Khz square wave of 200 V.

3 Result and Discussion

Fig. 1 shows optical micrographs of the sample I with/without switching field between crossed polarizers. With zero switching filed, the uniform dark and white states are achieved due to good alignment of liquid crystals [Fig.1(a) and (b)]. It means that the PSCOF structure is formed between two glass substrates. 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 a certain switching voltage, 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 switching field (>1 V/μm), one can obtain white state which means that the LC molecules have turned by 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 the 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 the uncured prepolymer in LCs. It is found that it requires at least 30 minutes 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 after applying bias field without UV exposure at 40 °C. It is quite clear the LC molecules have turned by 45° with respect to the rubbing direction. After UV exposure, the bias field was removed and the sample was cooled down to room temperature. The slow relaxation time in less cured sample without bias field is drop to 32.5 ms in biased sample. The value 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 in the phase-separated textures. 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 with no switching field did not show dark state different from that of unbiased one (sample I). Fig. 2(c) and (d) show that the 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 liquid crystal molecules is twisted between glass and

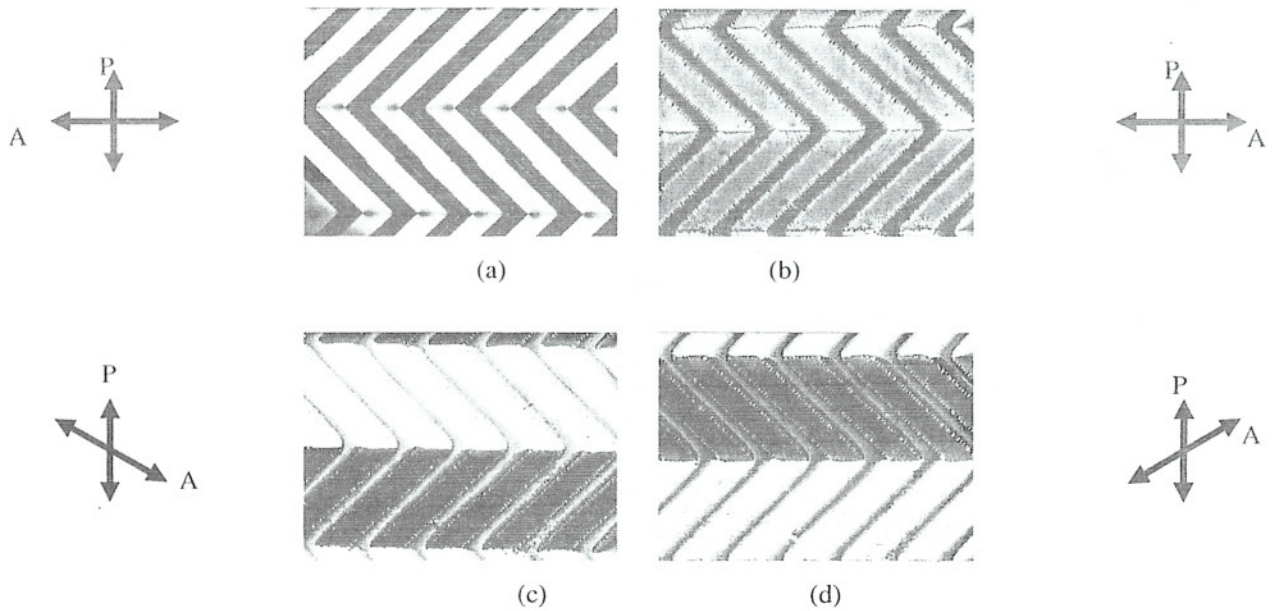
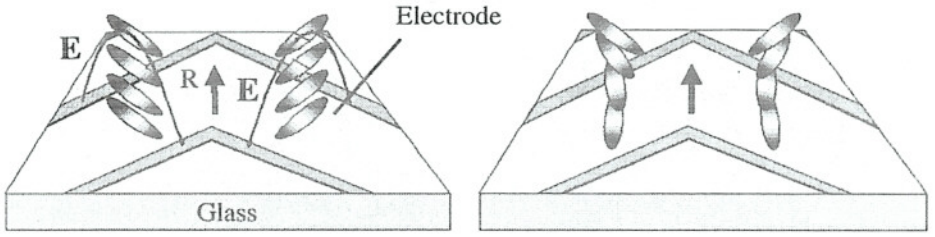


Fig. 2 Optical microphotographs of the cell before and after the second UV exposure. (a) 2 V/μm before UV exposure. (b)-(d) 0 V/μm after UV exposure with different geometry of analyzer. The P and A represent polarizer and analyzer, respectively.



(a) (b)

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.

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 to polymer layers by polymerization process. By applying bias field, the long axis of LC molecules are aligned along the electric field due to their positive dielectric anisotropy of LC molecules [Fig. 3(a)]. The second UV exposure stimulated the polymerization of uncured prepolymers which remain after the first UV exposure. In this 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, the LC molecules are oriented in the direction of polymer chains without electric field [Fig. 3(b)].

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. The fabrication and EO study of optimized TN structures with striped patterned IPS electrodes are under progress for the display applications. The result will be published elsewhere.

4. Conclusion

We reported an electric field effect on the formation of PSCOF structure which is utilized by anisotropic phase separation from LC and prepolymer mixtures. Application of bias field resulted in a significant change in the phase-separated textures. The liquid crystal molecules segregated into the inter-electrodes and formed twisted structure between glass substrate and polymer layer. The TN structure is the result of imprinting of LC alignment by the bias field to polymer layers during polymerization process.

Acknowledgement

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