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Multi-Domain Alignment of Liquid Crystal Using a Stamp of Anisotropic Morphology Fabricated by a Directional Polymerization of Reactive Mesogen

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We proposed a simple method to control liquid crystal (LC) alignments by a replication method of directional polymerization of reactive mesogen (RM). The RM polymer structures with nano-grooves were prepared by ultraviolet exposure to the RM mixed alignment layer in a LC cell and transferred to a polyimide by stamping method, which directly replicated the LC alignments of the LC cell. The transferred polyimide layer generated the stable multi-domain alignments of the LC without any aligning processes nor any electrode patterns.

Keywords liquid crystal display; replication; reactive mesogen; multi-domain alignment

1. Introduction

The uniform alignment of liquid crystal (LC) is one of the important characteristics for practical display application as well as for understanding of the fundamental phenomena such as the molecular ordering and the phase transition. Among the many methods of alignment techniques, a rubbing method has been widely used due to its cost effectiveness and strong anchoring characteristics [1, 2]. However, direct contact of the rubbing roller to the polymer substrate can deteriorate the surface properties of the alignment layer and induce electrostatic charge. Many kinds of approaches have been explored to achieve the uniform alignment without rubbing process such as Langmuir-Blodgett films, ultra-violet (UV), and ion-beam exposure [3–5]. In these methods, however, the complicated processes and/or the weak anchoring properties are inevitably involved.

Anisotropic surface morphology with periodic grooves was introduced to align the LC molecules based on the Berreman theory [6]. Various approaches to fabricate the nano/micro grooves have been reported such as laser interference lithography, e-beam lithography, and atomic force microscopy (AFM) lithography [7–8]. However, those lithography techniques took so long time to fabricate the large size devices. Recently, Kim *et al.* reported the fabrication method of nano-filament structure using the reactive mesogen (RM) in the LC

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cell [9]. By controlling the LC molecules on the RM mixed alignment layer by an external electric field during the UV exposure process, various characteristics can be controlled such as the pretilt angle, response time, and anchoring energy. Especially, the LC directions were directly replicated by the polymerized RM filaments [9].

In this work, we proposed the simple method to fabricate the nano-grooves by stamping method of the directional polymerization of the RM. The nano-groove structure was replicated from the polymerized RM filaments, which coincided with the LC alignments in the multi-domain LC cell. The transferred alignment layer generated the stable multi-domain alignments of the LC without any aligning processes nor any electrode patterns. The proposed technique is expected to be viable method to generate the complicated alignment patterns in the large area.

2. Experimental

We prepare the conventional vertically aligned (VA) LC cell to fabricate the master mold with nano-grooves as shown in Fig. 1. The indium-tin oxide (ITO) glass was cleaned with de-ionized water and detergent (Mucosol) and spin-coated with the polyimide (PI) alignment material (AL60702, JSR) mixed with the RM (RM257, E. Merck). After having baked onto a hot plate, the ITO substrates were rubbed using cotton roller and assembled in anti-parallel direction maintaining a cell gap by the glass spacers of about $3\text{ }\mu\text{m}$ thickness. The cell was filled with the nematic LCs (MLC-6608, E. Merck) with negative dielectric anisotropy ($\Delta\epsilon = -3.2$) at the isotropic temperature and cooled down to the room temperature. The RM monomers can align parallel to the LC direction due to those LC properties. Now, we can achieve the specific morphology by controlling the LC molecules during the polymerization process of the RM. After the LC injection, the LC cell was exposed to the UV light under an external electric field (10 V, 1 kHz with square waveform) for 30 min. In this situation, the LC molecules and the RM monomers were arranged parallel to the rubbing direction and the RM monomers were directionally polymerized forming nano-filaments [9]. Finally, we obtained the master mold with the nano-filaments of the polymerized RM after disassembling the LC cell and washing out the LC molecules with hexane.

The nanostructure of the RM morphology was replicated by polydimethylsiloxane (PDMS). Now, the PDMS replica used as a stamp and the PI layers were imprinted using the PDMS stamp during the imidization processes. After fully imidization process, anisotropic nanostructure was formed on a substrate. We transferred the nanostructure to the VA alignment layer of AL60702 and the planar alignment layer of SE7492 (Nissan). Using the patterned VA (PVA) cell [10], we also achieved the multi-domain anisotropic nanostructures using the same process. To characterize the transferred alignments, AFM and microscope were used and the LC cells were fabricated with the MLC-6608 with negative dielectric anisotropy and the ZKC-5085 (JNC) with positive dielectric anisotropy ($\Delta\epsilon = 3.8$).

3. Results

Figure 2 shows the AFM images of the fabricated RM morphology and transferred morphology to the AL60702. Based on the Berreman theory, a surface anchoring energy could

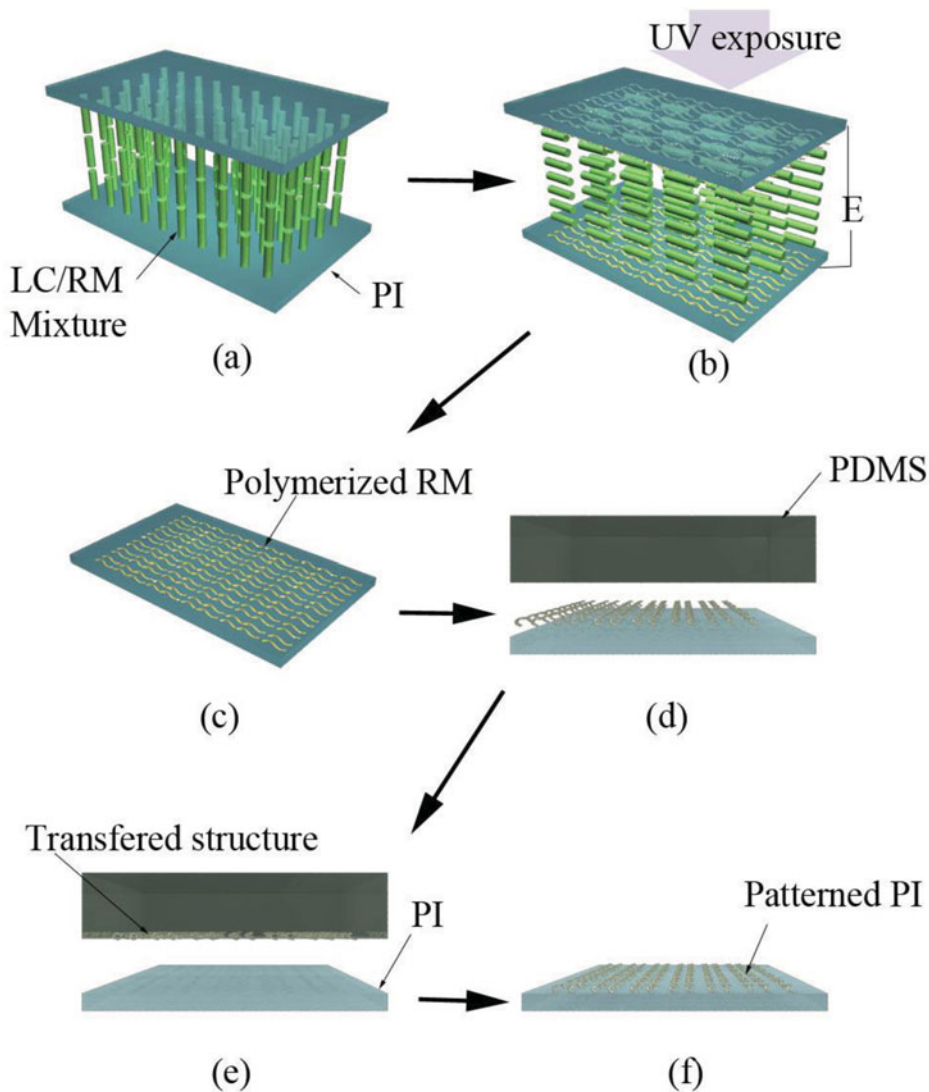


Figure 1. The fabrication process of the nanostructure alignment layer.

be written as [6]

$$W = \frac{2\pi^3 A^2 K}{\lambda^3} \quad (1)$$

where A , λ , and K are amplitude and pitch of the groove, and elastic constant of the LC. In our fabricated sample, the pitch and depth are about 700 and 60 nm, respectively. Using Eq. (1), the azimuthal anchoring strength was estimated to be $0.7 \cdot 10^{-5}$ N/m, which is sufficient anchoring strength to obtain the uniform alignment of LCs.

To confirm the aligning property of the transferred nanostructure, we fabricated the sandwiched LC cell with two nanostructure-transferred substrates in parallel direction.

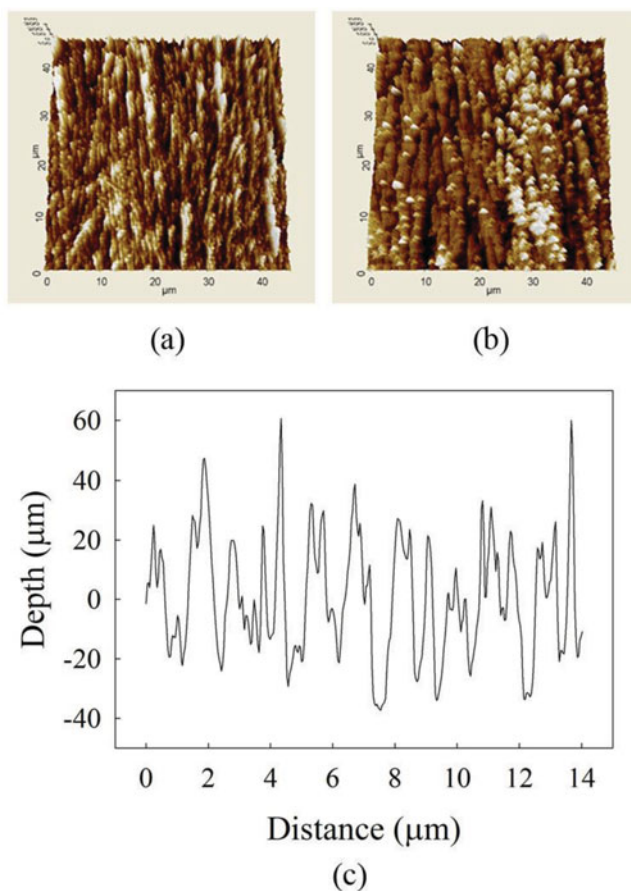


Figure 2. AFM images of (a) the PDMS mold surface and (b) the transferred PI surface. (c) cross-sectional distribution of the transferred PI surface.

The cell gap was maintained at about $3\ \mu\text{m}$ using glass spacers. The nematic LCs with the positive and the negative dielectric anisotropies were injected by capillary action at isotropic temperature. The MLC-6608 with negative dielectric anisotropy was used for the transferred AL60702 layer and the ZKC-5085 with positive dielectric anisotropy was used for the transferred SE7492 layer.

Figure 3 shows the polarized microscopic textures for two kind of LC samples. For the MLC-6608 sample (VA sample), the incident light was blocked under crossed polarizers because the LC molecules aligned perpendicular to substrates at initial state as shown in Fig. 3(a). By applying the electric field, transmittance gradually increased due to the birefringence of the LC cell. Similarly, the ZKC-5085 sample under planar alignment shows the bright at initial state and transmittance gradually decreased with increasing the applied voltage as shown in Fig. 3(b). To confirm the uniform alignment, we observed dark textures of the planar alignment states in both samples under crossed polarizers, where the groove direction is parallel to one of crossed polarizers; that is, texture under high applied voltage for the MLC-6608 sample and texture under no applied voltage for the ZKC-5085 sample. As shown in Fig. 3(c), we achieved the good dark textures in both samples.

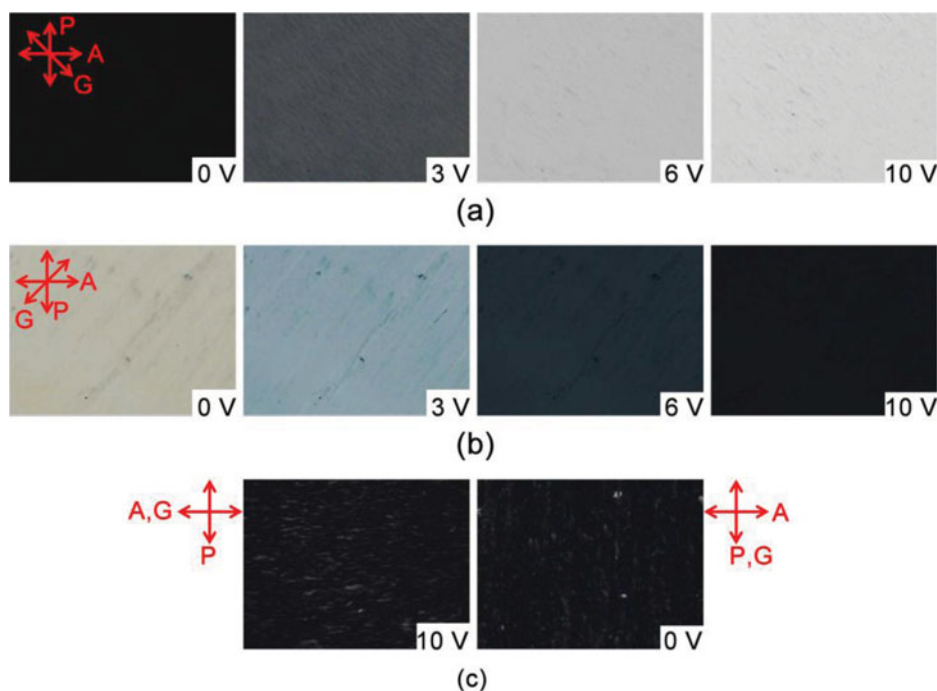


Figure 3. Polarized microscopic textures of (a) the vertical alignment, (b) the planar alignment samples, where the groove direction is rotated by 45° with respect to one of crossed polarizers. (c) Microscopic textures in the planar states in both samples, where the groove direction is parallel to one of crossed polarizers. The arrows depicted the optic axes of polarizers (P, A) and direction of the groove (G).

Using this lithography technique, we can also make the multi-domain structure of the liquid crystal. To fabricate the multi-domain structure, we use the PVA sample. In PVA mode, the electrode slits are alternatively arranged between top and bottom electrodes. As a result, the fringe fields are generated and thus uniform and multi domain structures can be achieved. Similar to the previous method, the MLC-6608 with negative dielectric anisotropy was injected into the PVA cell coated with the mixed RM alignment layer and the UV was exposed under applying the electric field.

Fig. 4 shows the fabricated multi-domain nanostructure using a conventional PVA cell. After UV exposure similar to previous processes, the multi-domain nanostructures were generated as shown in Fig. 4(a). The nanostructure represents four different directional orientations owing to the chevron type electrode formation of the PVA mode. After disassembling the cell and washing out the LC molecules with hexane, the multi-domain structures still remained (see Fig. 4(b)) and the structures were well transferred using PDMS (see Figs. 4(c) and (d)). To investigate the multi-domain structures, top substrate was rubbed along the x -axis, which is rotated by 45° with respect to the nanostructure direction. Note that no electrode pattern was introduced in the both substrates.

In case of the planar alignment LC cell (the rubbed top planar alignment and the transferred bottom planar alignment), the white state was observed under no applied voltage due to two different twisted configurations (45° and 135°) as shown in Fig. 4(e). Since the different twisted angles, even-odd effect was observed in the texture as shown in Fig. 4(f).

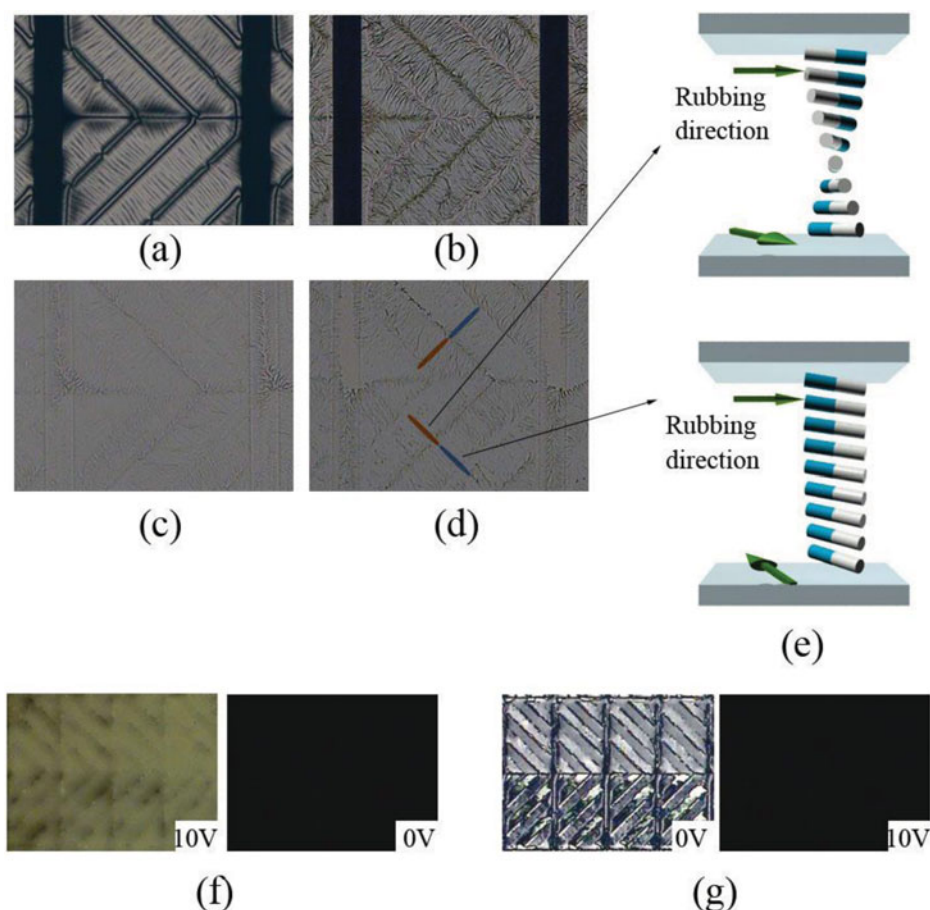


Figure 4. Microscopic textures of the nano-structures (a) before detached sample, (b) after detached sample, (c) the PMDS mold surface, and (d) the transferred PI surface. (e) Schematic diagrams of the two different twisted configuration corresponding to (d). The multi-domain LC textures for (f) the planar alignment and (g) vertical alignment modes.

Note that if the anchoring strength of the transferred alignment layer was too weak to form the twisted configuration, whole area would be dark since the rubbing axis was parallel to one of crossed polarizers. However, we observed the bright state and even-odd effect in the texture, and thus the transferred planar alignment layer produced the sufficient anchoring strength.

In case of the vertical alignment LC cell (the rubbed top vertical alignment and the transferred bottom vertical alignment), the white state was observed under the applied voltage as shown in Fig. 4(g). Contrary to the planar alignment case, the LC directors were not rotated sufficiently owing to the weak azimuthal anchoring strength in the vertical alignment layer [11]. The LC molecules were aligned in the mid-direction between the rubbed and nanostructured directions and thus the texture looked like two-domain planar structure as shown in Fig. 4(g).

4. Conclusions

We proposed a simple method to control the LC alignment by stamping method of the nano-groove structures generated by the directional polymerization of the RM. The directionally polymerized RM was directly replicated from the LC alignments. The multi-domain structure generated by complicated electrode patterns was easily reproduced through transferring to the conventional alignment layer without any aligning process nor electrode patterns. The alignment controlling method proposed here is expected to be a viable method to generate the complicated alignment patterns in the large area.

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