Patterning of liquid crystal alignment layers using selective dewetting process in a thermoplastic polymer film

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Abstract

We proposed a soft-lithographic method for aligning a liquid crystal (LC) in patterned azimuthal orientations. It is demonstrated that a thermoplastic polystyrene layer is patterned from a thermally stable polyimide layer via pressure-assisted capillary force lithography, which provides multidirectional LC alignment condition simply followed by a unidirectional rubbing process.

1. Introduction

The electro-optic (EO) properties of liquid crystal (LC) devices highly depend on a LC geometry determined by surface alignment conditions. Recently, patterning methods of a LC alignment layer for producing a multi-domain structure have attracted much attention for enhancing EO properties in many LC applications including a wide viewing LC display (LCD) [1,2], a transflective LCD [3], and diffractive LC devices [4]. There are several approaches for patterning a LC alignment surface including a selective rubbing method with photolithographic protecting layers [5], a photoalignment with masks [6], holographic methods, a dip pen nanolithography using an atomic force microscope tip [7], a microrubbing method with a metallic ball sphere [8,9], and chemical nanoimprinting methods [10]. However, conventional multi-domain alignment methods require complex procedures, which is not suitable for real applications.

In this paper, we propose a soft-lithographic method for patterning LC alignment layers. Using selective dewetting behavior above the glass transition temperature (T_g) of thermoplastic polymer, we produce a patterned polymer layer in tens of micrometer scale. To produce multi-directional easy axis distribution after unidirectional rubbing, isotatic polystyrene (i-PS) is used as the thermoplastic patterning material. It is demonstrated that PS layer on thermally stable polyimide (PI) layer can be precisely patterned by pressure-assisted capillary force lithography (PA-CFL) method [11]. On the patterned PS/PI substrate, LCs are orthogonally aligned with producing multi-domain LC structure.

2. Selective dewetting of PS film by pressure-assisted capillary force lithography

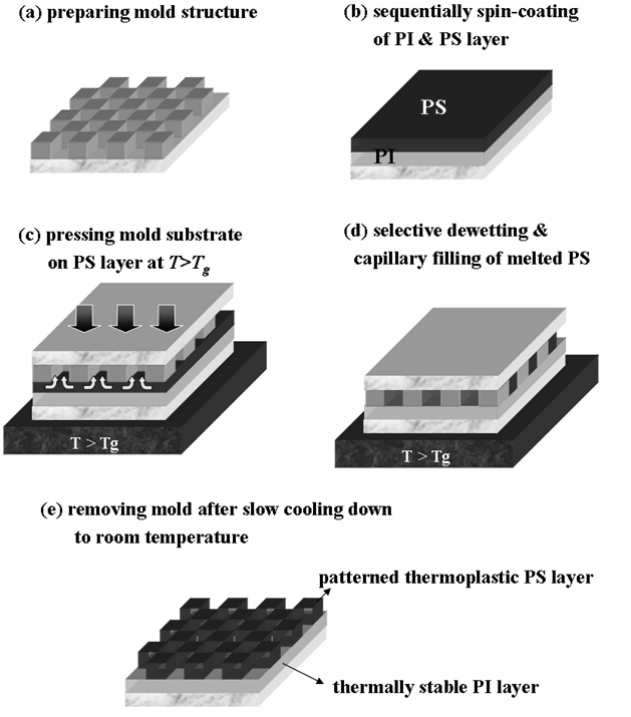

Figure 1. The schematic illustrations of pressure-assisted capillary force lithographic patterning of a thermoplastic PS layer on a thermally stable PI layer.

The PA-CFL procedures for preparation of patterned LC alignment layers are shown in Fig. 1. Our patterning procedures were soft-lithographically executed without any etching process and any photo-masking process. First, PI and PS layers were sequentially spin-coated. In our experiment, a homogeneous LC alignment PI, RN1199 (Nissan Chemical Ind.) was used for the thermally stable base polymer film. As a patterning material, a thermoplastic isotatic PS (i-PS, Scientific Polymer) diluted in toluene was used. Then, a patterned mold structure was contacted on the prepared PS/PI bilayer films and it was slightly pressed down to achieve conformal contact. The patterned mold structure was fabricated by conventional photo-lithographic method. When the combined structure was heated above the glass transition temperature (T_g) of i-PS, the PS film became melted state and the mold structure sank down to the PI layer as shown in Fig. 1 (c). During this annealing procedure, the i-PS in the areas where the mold structure was closet to the base substrate was dewetted from the PI layer and was filled into the mold spacing areas by the pressure-assisted capillary filling. In our experiment, T_g of i-PS was about 100 ^{o}C and the PI layer was not affected in that temperature range. After the dewetting process was fully accomplished, the combined structures were slowly cooled down to room temperature and then the mold was removed. Finally, the patterned PS layer was prepared on the thermally stable PI layer as shown in Fig. 1 (e).

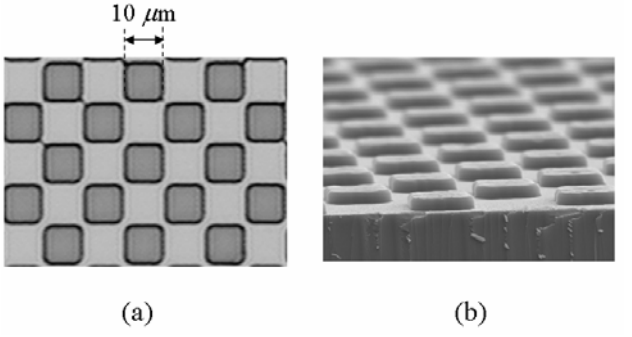

Figure 2. (a) Microscopic image of the mold structure. (b) 3-dimensional AFM image of the mold structure.

The patterned mold substrate was fabricated by a photo-lithographic method using negative photoresist of SU-8 (MicroChem) as shown in Fig 2. The fabricated SU-8 mold substrate had check patterns in 20 μm period. If the molecular weight of the thermoplastic material is sufficiently low and the thickness of the thermoplastic polymer film is very thin, the capillary force lithographic pattern can be obtained with elastomeric mold without any pressing [11]. However, in our case, the molecular weight of the i-PS was relatively large with the value of 400,000. Therefore, weak pressure with rigid mold should be required to obtain complete PS patterns.

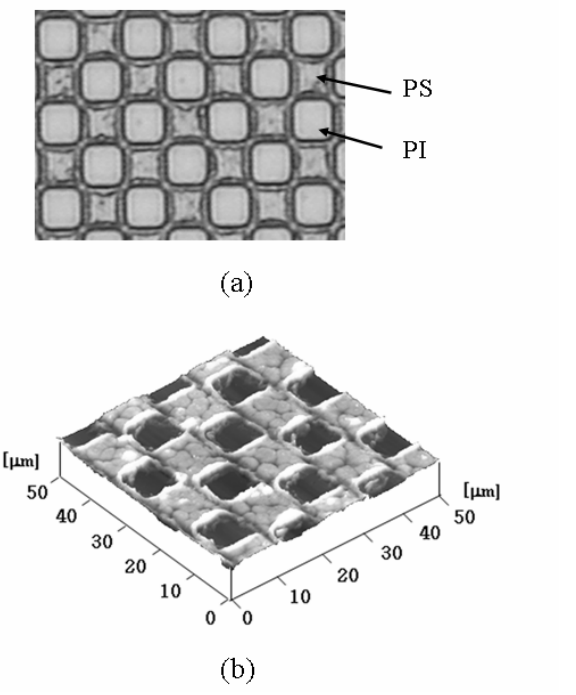

Figure 3. (a) Microscopic image of patterned PS layer on the PI layer. (b) 3-dimensional AFM image of the patterned PS/PI surface.

Figure 3 shows the patterned PS/PI surface. The areas where the mold was contacted were uncovered by the lower PI layer. In those areas, the PS was completely dewetted and moved between the mold structures by the pressure-assisted capillary filling. The patterned PS layer had check patterns in 20 μm period with the reverse structure of the mold. Our PA-CFL patterning method had an advantage that the patterning procedures were not affected by the solvent types in the patterning materials, which acts as obstacles degrading patterning resolution in other types of soft-lithographic patterning methods. The thickness of the patterned PS layer was about 200 nm.

3. Multi-domain LC structure by the patterned alignment layer

Our i-PS had 99% of the phenyl side groups on one side of the backbone as shown in Fig. 4 (a). Figure 4 (b) shows the LC cell texture where the LC cell was fabricated with the anti-parallel rubbed PS and PI layers. The bright and dark states of the polarizing microscopic images under the crossed polarizers and the parallel polarizers, respectively, showed that the LC cell had a twisted nematic (TN) structure and the easy axis on the i-PS surface was generated in a direction perpendicular to the rubbing direction. For comparison, LC cell textures where the LC cell was fabricated with anti-parallel rubbed atatic PS (Fig. 4 (c)) and PI layer were presented in Fig. 4 (d). The polarizing microscopic images of Fig. 4 (d) showed that LC cell had a homogeneously planar structure and the LC molecules on the atatic PS layer were aligned along the rubbing direction. Since the PI layer aligned LC molecules along the rubbing direction, i-PS should be used as patterning PS layer to produce multi-domain LC structure after unidirectional rubbing.

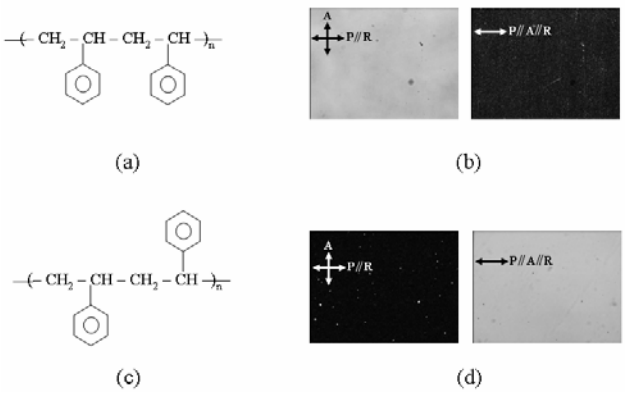

Figure 4. (a) and (c) are molecular structures of isotatic PS (i-PS) and atatic PS (a-PS), respectively. (b) Polarizing microscopic images of LC cell where the LC is aligned between anti-parallel rubbed PI and i-PS layer. (c) Polarizing microscopic images of LC cell where the LC is aligned between anti-parallel rubbed PI and a-PS layer.

We produced 10 μm-square PS pattern on a PI layer. The patterned substrate was assembled with unpatterned PI layer, where two substrates were orthogonally rubbed as shown in Figs. 5 (a) and (b). A nematic LC (NLC) was filled into the cavity in an isotropic phase of the NLC. In our experiment, the nematic-isotropic transition temperature of the NLC was lower than T_g of i-PS. Thus, the PS patterning and the rubbing effect on the PS layer did not affected by the NLC filling process. Figures 5 (c) and (d) show the polarizing microscopic images of the LC textures under the crossed polarizers and the parallel polarizers, respectively, where two domains of LC structures in square patterns of 10 μm could be observed. In Fig. 5 (c), the dark and the bright regions corresponded to the LC textures on the patterned PS and PI layers, respectively. When we changed the optical instruments from the crossed polarizers to the parallel polarizers, the bright and the dark regions changed to each other, which meant that the LCs on the patterned PS layer had a homogeneous planar structure and those on the patterned PI layer had a TN structure.

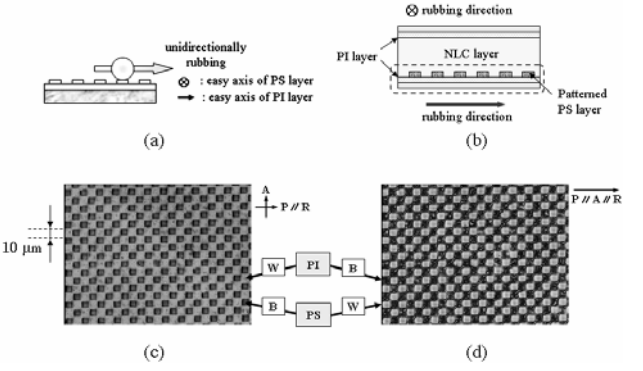

Figure 5. (a) Schematic illustration showing the easy axis direction on the patterned PS/PI layer after unidirectional rubbing. (b) The multi-domain LC cell structure fabricated by a patterned PS/PI surface and unpatterned PI surface. (c) and (d) are the polarizing microscopic images of LC textures (Fig. (b)) observed under the crossed polarizers and the parallel polarizers, respectively.

Figure 6 shows the effect of the multi-directional easy axis distribution on the patterned PS/PI surface on the viewing angle properties of the LC cell. Figures 6 (a) and (b) are the viewing angle properties of hybrid-aligned LC cells, where the planar LC anchoring parts in Figs. 6 (a) and (b) were promoted by a homogeneous LC alignment PI layer and an i-PS layer, respectively. Figure 6 (c) was obtained by a LC cell fabricated by a homeotropic LC alignment PI

layer and a patterned PS/PI layer. In all the samples, the rubbing directions were identically executed along the y-axis as shown in Fig. 6.

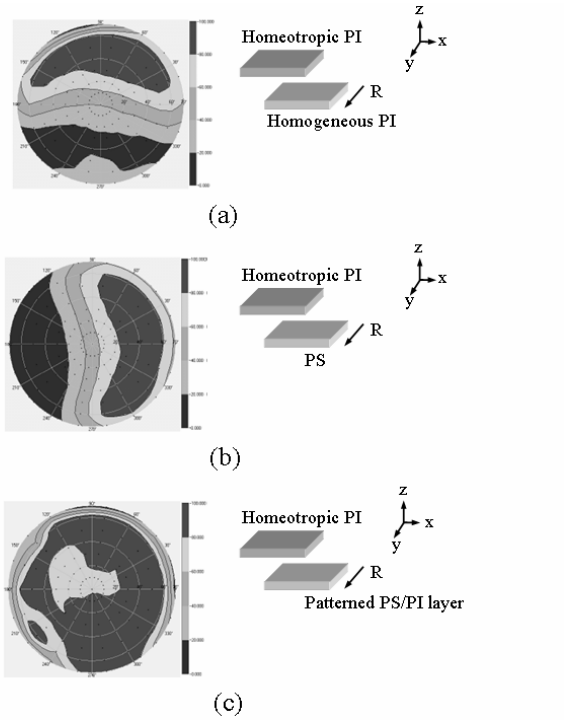

Figure 6. (a) and (b) are viewing angle properties of the hybrid-aligned LC cells fabricated by homeotropic PI/homogeneous PI layers and homeotropic PI/PS layers, respectively and their cell structures. (c) is viewing angle property of multi-domain LC cell where the optic axis in each domain are orthogonal to each other. In (a), (b), and (c), the rubbing directions are identically along the y-axis.

5. Conclusion

We proposed a LC alignment layer patterning method for producing multi-domain LC structure. By facilitating difference in the thermal stability and the rubbing-induced easy axis generation between the PS and PI layers, multi-directional LC alignment could be easily obtained. The proposed PA-CFL method has merits in its simplicity in fabrication as well as its high pattering resolution, which is assumed to be applicable to sub-micrometer patterning. Our patterning method would be very useful for improving the performance of LC devices via manipulation of patterned LC geometries.

6. Acknowledgements

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7. References

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