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Patterned Alignment Layers by Capillary Force Lithography for Multi-domain Liquid Crystal Structures

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We proposed a soft-lithographic technique for patterning liquid crystal (LC) alignment layers. It was demonstrated that a thermoplastic polystyrene layer was patterned on a thermally stable polyimide layer via pressure-assisted capillary force lithography. The patterned surface provided multi-directional LC alignment condition simply after a unidirectional rubbing process.

Keywords: liquid crystal; liquid crystal alignment; multi-domain liquid crystal; polyimide; polystyrene; pressure-assisted capillary force lithography

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INTRODUCTION

Recently, several types of multi-domain liquid crystal (LC) structures have been proposed to enhance or modify electro-optic (EO) properties of LC-based devices. In LC displays (LCDs), conventional viewing angle problems can be solved by azimuthally distributed LC orientations [1,2]. In transflective LCDs, the amounts of retardation in transmissive and reflective parts can be tuned by controlling surface pretilt of LCs differently in each part [3]. Electrically controllable, diffractive LC devices are achieved by periodically modified LC orientations [4]. Since LC structure in bulk is determined by surface alignment condition, patterned LC alignment layer is essentially required in obtaining multi-domain LC structures. As patterning methods to modify LC anchoring spatially, mechanical scribing methods with atomic force microscope tip [5–8] or metallic ball sphere [9,10], and optical alignment methods with photosensitive materials [11] have been proposed. However, such conventional approaches are not attractive for real applications due to their complex procedures requiring long processing time or their low stability in LC anchoring.

In this article, we produced multi-directional easy axes on a LC alignment layer using selective dewetting process of a thermoplastic polystyrene (PS) layer on a thermally stable polyimide (PI) layer via a pressure-assisted capillary force lithography method (PA-CFL) [12]. With the proposed method, the LC alignment layer can be patterned in tens of micrometer period. On our patterned PS/PI surface, multi-domain LC structure can be simply obtained only by unidirectional rubbing process facilitating orthogonal easy axis generation on PI and PS surfaces.

EXPERIMENTAL

The PA-CFL procedures for preparing patterned LC alignment layers are shown in Figure 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 and fully cured. 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. The average molecular weight of the i-PS was about 400,000. Then, a patterned mold structure was contacted on the prepared PS/PI bilayer films and it was slightly pressed down to achieve conformal contact.

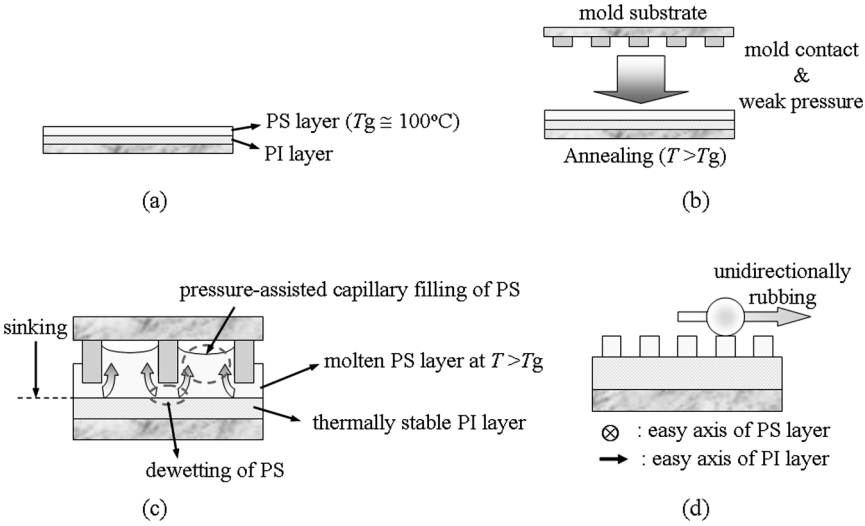

FIGURE 1 Illustrations of pressure-assisted capillary force lithography (PA-CFL) method for patterning LC alignment layers: (a) Preparation of bilayer films (PS on PI). (b) Contacting mold substrate on the prepared bilayer films with weak pressure at above the glass transition temperature of the PS. (c) Schematics of PS patterning by the PA CFL method. (d) Multi-directional easy axis formation on the patterned LC alignment layer by unidirectional rubbing process.

The patterned mold structure was fabricated by conventional photolithographic method with photoresist SU-8 (MicroChem. Co.). When the combined structure was heated above the glass transition temperature (T_g) of the i-PS, the PS film became melted state and the mold structure sank down to the PI layer as shown in Figure 1 (c). During this annealing procedure, the melted 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 by the pressure-assisted capillary filling [12–14]. In our experiment, T_g of the i-PS was about 100°C and the PI layer was not affected in our annealing 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 polymer surface was unidirectionally rubbed in a conventional method. Since the i-PS and the PI align LCs, perpendicular and parallel to the rubbing direction, respectively, LCs are aligned orthogonally to each other on the patterned PS/PI layers.

RESULTS AND DISCUSSION

Figure 2 (a) shows the microscopic image of the patterned PS/PI surface, where the PS layer was periodically dewetted from the PI surface. In obtaining the PS/PI pattern of Figure 2 (a), the patterned mold with the 10 μm periodic lines was used. Figure 2 (b) shows the 3-dimensoinal AFM image of the PS/PI surface patterned in a square type, where the dark and bright areas of the image were the patterned lower PI and the upper PS surfaces, respectively. The average thickness of the patterned PS layers was about 200 nm. The thickness of the PS pattern edges was thicker than the average thickness of the PS patterns. On the patterned PS surfaces, several domain-like patterns were observed, where the average domain size was about 7 μm. But, the LC alignment on the PS surface could be obtained uniformly irrespective of the domain-like PS surface patterns. Figures 2 (a) and (b) show that any type of PS patterns on the PI layer can be easily fabricated by the proposed PA-CFL method.

Figure 3 (a) shows the multi-domain LC cell structure fabricated with the patterned PS/PI substrate. The patterned substrate was unidirectionally rubbed as depicted in Figure 3 (a). As the other LC alignment layer, a homogeneously planar LC alignment PI layer was uniformly spin-coated and the substrate was rubbed in a direction orthogonal to the rubbing direction of the patterned substrate. Two substrates were assembled and the thickness of the cell gap was maintained with 10 μm glass spacers. As a nematic LC (NLC) material, E7 of E. Merck was filled into the cavity by capillary filling above the

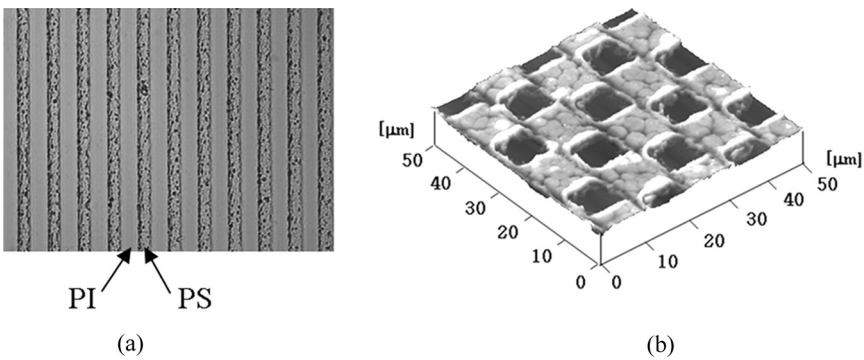

FIGURE 2 (a) The microscopic image of the line-patterned PS/PI surface, where the periodicity of the line patterns is 10 μm. (b) The 3D-AFM image of the patterned PS/PI surface, where the periodicity of the pattern is 20 μm.

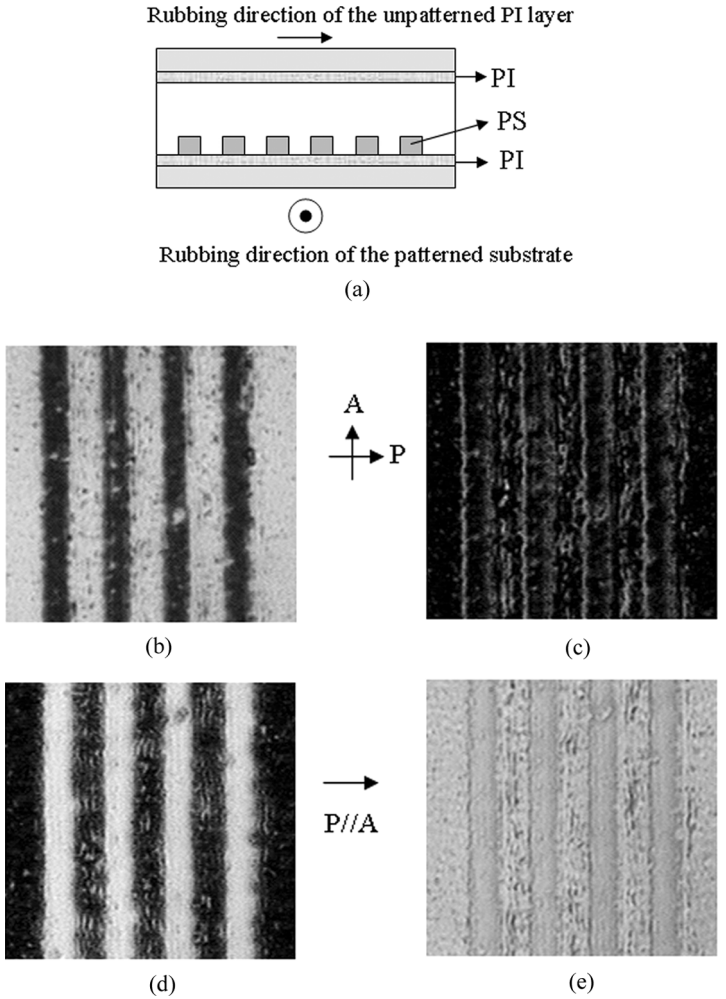

FIGURE 3 (a) The schematic of the multi-domain (TN/ECB) LC structure by the patterned PS/PI layer and a unpatterned PI layer. (b) and (c) are the polarizing microscopic images of multi-domain (TN/ECB) LC textures under the crossed polarizers, obtained at applied voltages of 0 V and 6 V, respectively. (d) and (e) are the polarizing microscopic images of the same sample under the parallel polarizers, obtained at applied voltages of 0 V and 6 V, respectively.

nematic-isotropic transition temperature ($T_{NI} = 60.5^{\circ}C$) of the NLC to avoid flow-induced LC anchoring. The T_{NI} of E7 was sufficiently lower than T_g of the i-PS used in our experiment. Therefore, the PS patterns

and the rubbing-induced LC anchoring on the PS surface were not affected by the thermal treatment for the LC filling.

Figure 3 (b) and (c) show the polarizing microscopic image of the multi-domain NLC cell, observed through the crossed polarizers in the absence and the presence of an applied voltage, respectively. The NLC textures of Figures 3 (d) and (e) were obtained between the parallel polarizers with the same NLC sample. The polarization of the incident light was parallel to the rubbing direction of the unpatterned PI layer. In our cell condition, the NLCs on the patterned PS and PI surfaces had a uniform-planar structure and a 90°-twisted nematic structure, respectively due to the patterned PS/PI surface. Between the crossed polarizers, the textures on the patterned PS and PI surfaces showed the dark and the bright states, respectively. When we changed the polarizers into the parallel configuration, the dark and bright states in each area were changed reversely into the bright and dark states, which meant that the polarization state propagating through the NLCs on the patterned PI surface was rotated by 90°, whereas, the polarization state propagating on the patterned PS surface kept the incident polarization state. When the applied voltage was increased to 6 V, the whole textures became dark and bright states under the crossed and parallel polarizers, respectively, as shown in Figure 3 (c) and (e). Notice that such multi-domain structure was obtained by single rubbing process on the soft-lithographically patterned layer. The NLC alignment textures on the patterned PI layer were relatively poorer than those on the patterned PS layer, which might originated in the remnants of PS on the PI layer. Such problem could be solved by using a PS with low molecular weight because the dewetting and diffusion processes during the CFL patterning could be more easily obtained when the molecular weight of a thermoplastic polymer became lower [13].

CONCLUSIONS

We proposed a simple patterning method on the LC alignment layer for producing multi-domain LC structure. By facilitating difference in the thermal stabilities and the rubbing-induced easy axis generation of the PS and PI layers, multi-directional LC alignment could be easily obtained. The proposed PA-CFL method had the merits in simple fabrication procedures as well as high patterning resolution, which could be applied to sub-micrometer patterning [13,14]. Our patterning method would be very useful for improving performances of LC devices via manipulation of patterned LC geometries.

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