Surface modification method for controlling liquid crystal alignment

Hak-Rin Kim[1], June-Yong Song[2], Kwang-Soo Bae[3], and Jae-Hoon Kim[2,3*]
[1]School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu 702-701, Korea
[1]TEL:82-53-950-7211, e-mail: rineey@ee.knu.ac.kr.
[2]Dept. of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea
[3]Dept. of Information Display Engineering, Hanyang University, Seoul 133-791, Korea
[*]TEL:82-2-2220-0343, e-mail: jhoon@hanyang.ac.kr.

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Abstract

We propose a soft-lithographic patterning method for producing a multi-domain liquid crystal (LC) alignment. The LC alignment polyimide layers are periodically patterned in the pixel boundaries by a micromolding-in-capillaries method. In our structure, the initially homeotropic LC orientations in the pixel areas are changed to axially symmetric LC domains due to the symmetric pretilt of LC molecules on the pixel boundaries.

1. Introduction

Recently, several types of multi-domain liquid crystal (LC) structures with spatially diversified optic axes of the LC layer have been proposed to enhance or modify electro-optic properties of LC-based devices[1,2]. Multi-domain LC structures combined with compensation films are essential features to solve limited viewing angle problems in display applications. Among the multi-domain LC structures, an axially symmetric multi-domain LC structures would exhibit the most ideal viewing angle symmetry due to equally distributed LC orientation in an azimuth plane[3-5]. In previous approaches to obtain symmetric LC distributions, photo-lithographically patterned protrusions, pixel-boundary wall structures by phase-separation from LC/pre-polymer mixtures[3] or patterned electrode structures[4] are required.

In this work, it is demonstrated that axially-symmetric multi-domain structures can be simply produced by soft-lithographically patterned LC alignment layers. In our structure, LCs in pixel areas are homeotropically aligned without rubbing and pretilt. In field-on state, the field-induced tilting of the LCs is determined by pretilt of LCs in pixel boundaries. Depending on the patterning conditions in the pixel boundaries, the LC textures in the pixel areas can be controlled by pre-transition effects of the LC molecules in the pixel boundaries.

2. Field-induced LC reorientation by patterned surfaces

Figure 1 shows the schematic diagram of fabrication procedures for preparing our patterned LC alignment layer by micromolding in capillaries (MIMIC)[6]. First, a homogeneous LC alignment polyimide (PI) layer is uniformly spin-coated on an ITO glass substrate. After curing of PI, the homogeneous LC alignment PI surface is unidirectionally rubbed to produce the surface pretilt in LC anchoring (Fig. 1(a)). On that surface, an elastomeric poly(dimethylsiloxane) (PDMS) mold structure with micro-channels is placed, where the direction of the micro-channels is orthogonal to the rubbing direction of the base PI (Fig. 1(b)). Into the insets of the PDMS mold channels, a homeotropic LC alignment PI in solvent is filled by the capillary action (Fig. 1(c)). After the filling process is completed, the solvent of the homeotropic LC alignment PI filled in mold channels is evaporated by pre-baking process of the PI. Then, the mold structure is carefully removed. Due to very stable interfacial properties of the PDMS, the pre-baked homeotropic PI patterns are not damaged during this step. The patterned homeotropic LC alignment PI layer is fully cured at hard-baking temperature. Finally, the patterned homeotropic PI layer is prepared in the pixel areas, which is not rubbed.

Figure 2 shows the polarizing microscopic images of the LC textures where the LCs are aligned between the patterned layer (Fig. 1(d)) and a non-rubbed homeotropic PI layer. As a nematic LC (NLC), MLC6610 from E. Merck with a negative dielectric anisotropy was used. In field-off state, the LCs are aligned with the VA mode on the patterned pixel areas. On the patterned pixel boundaries, the LCs are aligned with the hybrid mode, which can be shown with the bright texture of Fig. 2(a). When we apply an electric field to the cell, Fig. 2(b) shows that the completely dark texture on the patterned pixel areas is changed to a uniform bright texture without generating Schlieren textures although there is no surface treatment for pretilt on both surfaces. Such behavior can be explained by the lateral domain propagation from the pattern edges. The LC molecules with the hybrid mode response to lower voltages than those with the VA mode. The pretilt of the LC molecules on the rubbed homogeneous PI patterns determines the field-induced tilting direction of the non-rubbed homeotropic PI. On both edges, the pretilt directions are same. Thus, there is no domain wall.

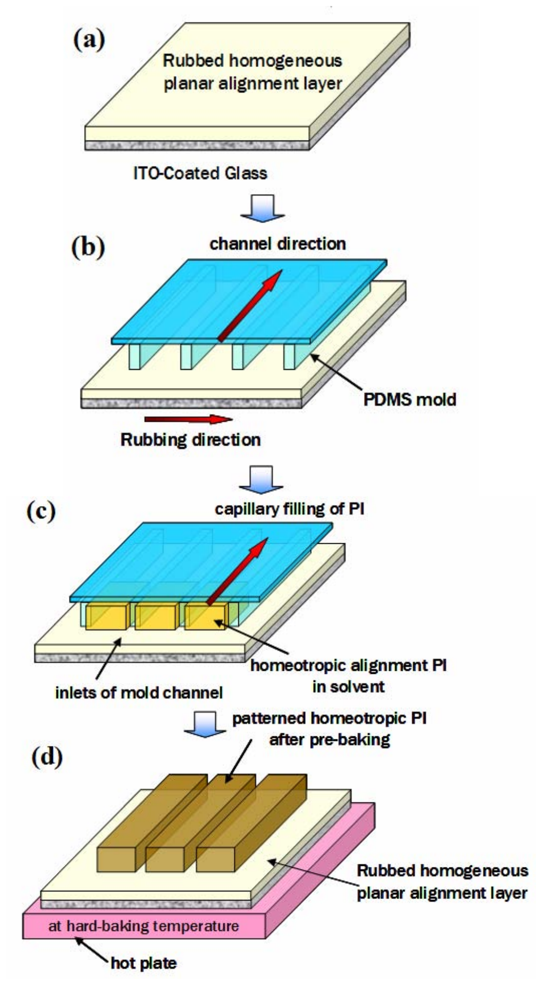


Fig. 1. The schematic diagram of LC alignment layer patterning by the MIMIC method.

With a pair of the patterned substrates, we can simply produce complex multi-domain textures. Figure 3 shows the scheme of the cell assembly with the patterned substrates (Fig. 1(d)) where the rubbing directions of the homogeneous PI layer of two patterned substrates are orthogonal to each other. In the pixel area, the LCs are aligned with VA mode without pretilt. The pixel areas are surrounded by the LCs with the hybrid mode and the LCs with the twisted nematic (TN) mode. Among them, the pretilt directions of the boundary LC molecules with the hybrid mode determine the field-induced tilting direction of the LCs in the pixel areas.

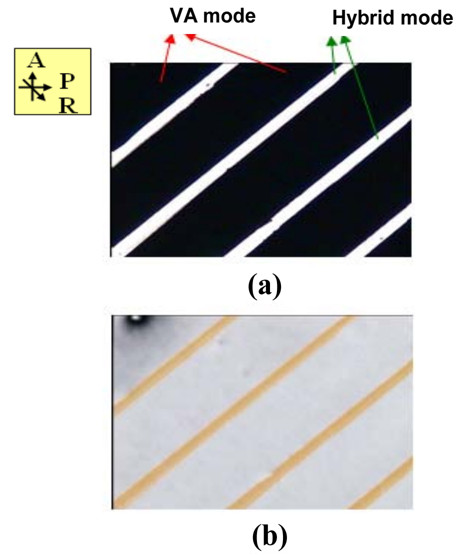


Fig. 2. The polarizing microscopic images of the LC textures where the LCs are aligned between the patterned PI substrate (Fig. 1(d)) and the non-rubbed homeotropic PI substrate: (a) field-off state, (b) field-on state.

Figures 4(a) and (b) show the polarizing microscopic images of the LC textures without and with an applied voltage, respectively. Without an applied voltage, the pixel area shows the completely dark state. In the areas of the pixel boundaries, bright states are obtained due to retardation of the LC molecules aligned with the hybrid and TN modes. When we apply 10 V to the sample, each pixel area shows symmetric four dark brushes, which means that the LC molecules are aligned in a direction parallel to one of polarizers. When we rotated the sample by 45^{o}, the LC texture shows the same dark brushes with Fig. 4(b). This means that the LC distribution in the field-on state is axially symmetric in an azimuth plane. The effects of the domain propagation from the pixel boundaries are the strongest along the white lines (Fig. 4(b)) bisecting the pixel areas. Between two bisecting lines, the tilting directions are determined by the competition of the orthogonal boundary effect. In this sample, the tilting direction propagated from the parallel sides of each pixel is one direction. Thus, the viewing angle enhancement is obtained in two directions due to orthogonal pixel boundaries. The LC distributions and the EO effects are confirmed by 3-D simulations with the proposed structure.

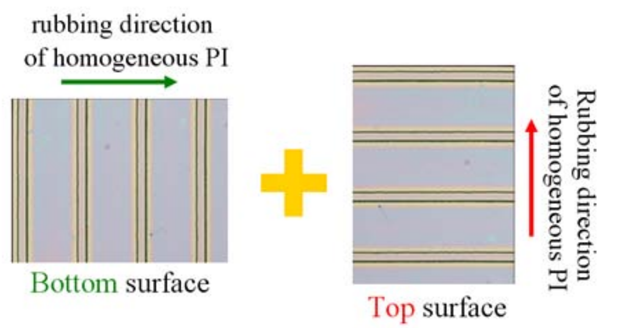


Fig. 3. The schematic diagram showing our cell assembly for producing multi-domain LC structure.

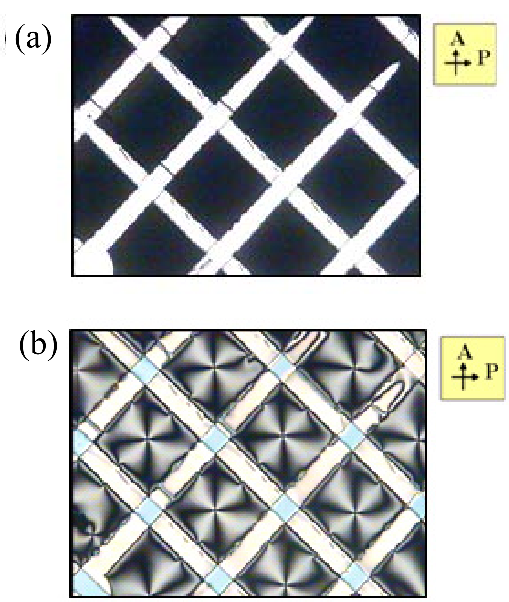


Fig. 4. The polarizing microscopic images of the LC cell fabricated with the scheme of Fig. 3: (a) field-off state, (b) field-on state.

3. Axially symmetric LC domain formed by patterned surface structures

To obtain an axially symmetric LC structure with four domains, we patterned protrusion with the homeotropic PI in a periodic line shape on a non-rubbed homeotropic PI layer. The procedures of patterning are the same with Fig. 1 except that the PI patterns produced by the MIMIC method are pixel boundaries in this case. One of merits in the soft-lithographic patterning methods is that a polymer structure with an arbitrary shape can be easily obtained.

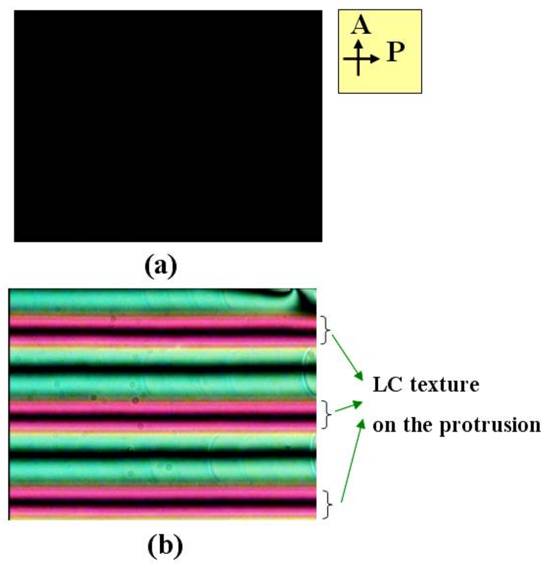
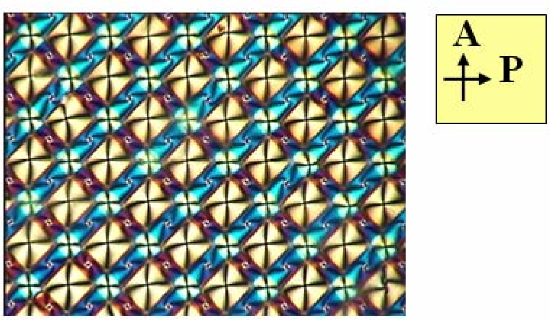


Fig. 5. The polarizing microscopic images of the LC texture. The LCs are aligned between the patterned surface with protrusions fabricated by a homeotropic PI in a periodic line shape and the non-rubbed homeotropic PI layer: (a) field-off state, (b) field-on state (5 V).

Figure 5 shows the LC textures observed by the polarizing microscope where the LCs are aligned between the patterned surface and the non-rubbed homeotropic surface. In the field-off state, the texture shows completely dark state since the patterned protrusion was formed by the homeotropic PI and the pretilt direction by the patterned protrusion in the pixel boundaries is parallel to one of polarizers. In the field-on state, the protrusion of the homeotropic PI determines the field-induced tilting direction of the LC molecules aligned between two non-rubbed homeotropic PI substrates. Figure 5(b) shows that there are domain wall lines parallel to the protrusion. This means that the tilting directions by the domain propagation from the pixel boundaries are opposite to each other in this case.

Figure 6 shows the polarizing microscopic images of the LC textures where the LCs are aligned between a pair of the patterned substrates. To induce the effects of the orthogonal domain propagations from the top and the bottom protrusions, the patterned substrates are assembled orthogonally to each other. Figure 6(b) shows the LC texture at an applied voltage of 5 V. In this case, the LC molecules in the pixel areas are axially symmetric in four domains at applied voltages and the viewing angle is enhanced in four directions.

(a)



(b)

Fig. 6. The polarizing microscopic images of the LC textures. The LCs are aligned between a pair of the patterned surfaces with protrusions of a homeotropic PI in a periodic line shape: (a) field-off state, (b) field-on state (5 V).

4. Summary

In summary, we demonstrated the soft-lithographic patterning method for controlling field-induced tilting direction of LC molecules in VA mode. Especially, we could simply produce the axially symmetric multi-domain structures at applied voltages by assembling two identically patterned substrates orthogonally to each other. It is expected that the proposed method would be useful in enhancing EO properties of LC-based devices by modifying LC modes.

5. References

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