P-172: Micro-Contact Printing Method for Multi-Domain Liquid Crystal Alignment

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Abstract

We proposed a simple method for patterning alignment layers to produce multi-domain liquid crystal (LC) alignment. By micro-contact printing method, we produced multi-directional easy axis on the alignment layer using conventional LC alignment materials. Our printing method would be a very useful tool for designing a LC mode in wide-viewing LCDs or transflective LCDs.

1. Introduction

The electro-optical (EO) properties of liquid crystal (LC) devices highly depend on a LC geometry determined by a surface alignment condition. Recently, patterning methods of a LC alignment layer for producing a multi-domain structure have attracted much attention for enhancing the EO properties in many LC applications including a wide viewing LC display, a transflective display [1], and diffractive LC devices.

There are several approaches for patterning a LC alignment surface including a selective rubbing method with photolithographic protecting layers [2], a photoalignment with masks, holographic methods, a dip pen nanolithography using an atomic force microscope (AFM) tip [3], a microrubbing method with a metallic sphere [4,5], and chemical nanoimprint method [6,7]. However, conventional multi-domain alignment methods are unattractive because of cumbersome multiple processing techniques and/or long processing time in real display applications. In order to apply chemical nanoimprint methods to practical applications, the thermal stability and durability of LC alignments have to be further examined.

In this work, we propose a simple patterning method for multi-domain LC alignment. By micro-contact printing method, we produced multi-directional easy axis on the alignment layer using conventional LC alignment materials such as poly (vinyl alcohol) and polyimide. Our simple micro-contact printing method is suitable for large area patterning in mass production.

2. Micro-Contact Printing of Alignment Layers

In our fabrication process, the patterning of an alignment layer was executed by single step of contact printing without any etching process and any photo-mask process, as shown in Fig. 1. First, a patterning material (alignment agent I) was spin-coated on a patterned mold structure. Before transferring the patterning material with micro-contact printing, the base substrate to be patterned was preheated to pre-baking temperature of the patterning materials, which enhances the adhesion of the patterning material to the base substrate. After placing the mold structure with alignment layer on the base substrate, the patterning material was wholly transferred to the base substrate by keeping the contact at pre-baking temperature of the patterning material.

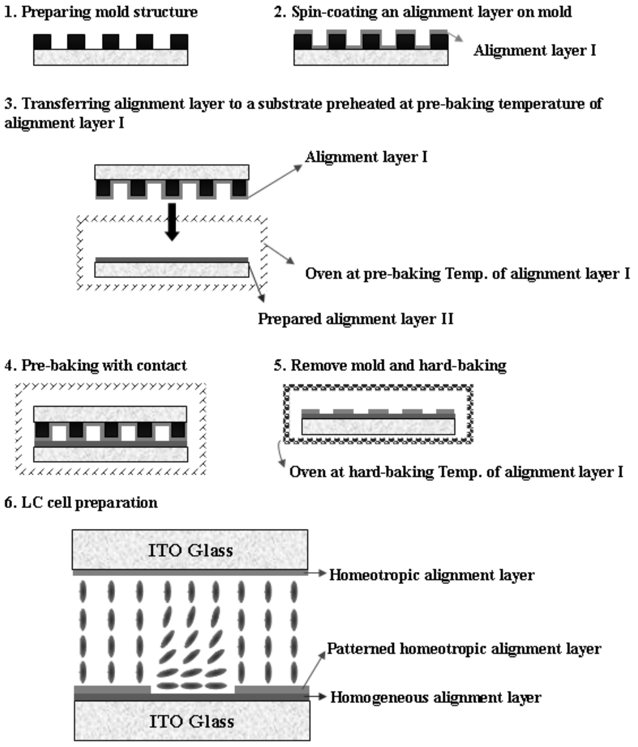

Figure 1. Schematic illustrations of micro-contact printing procedures for patterning LC alignment layers.

Then, the mold substrate was removed and the substrate with the patterned layer was cured at a hard-baking temperature of the patterning material. With the proposed method, the LC anchoring at the surface can be spatially modified in easy axis orientation, pretilt, and surface anchoring energy by selecting different patterning materials and the base surface conditions. We note that the method can be applied to the substrate with bare ITO or coated polymers.

We patterned various types of homogeneous alignment materials as well as homeotropic alignment materials on a bare ITO substrate or polymer surfaces. A patterned mold substrate was fabricated by a photo-lithographic method using negative photoresist of SU-8 (MicroChem). It was observed that surface wetting difference of patterning material between a mold surface and a surface of the base substrate for patterning had an important role in obtaining uniform patterning of alignment layers. Fig. 2 shows contact angle measurement results of a homeotropic alignment material (AL1H659, JSR Co.) on bare ITO, SU-8 used for mold patterning, and a homogeneous alignment layer

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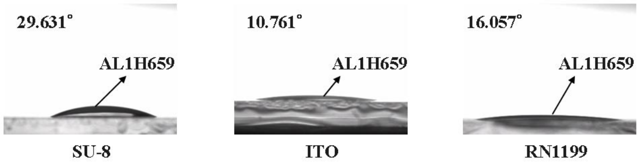


(a) (b) (c)

Figure 2. Contact angles of AL1H659 (patterning material for homeotropic anchoring) on (a) SU-8 surface (mold material), (b) ITO surface, and (c) homogeneous alignment polyimide layer.

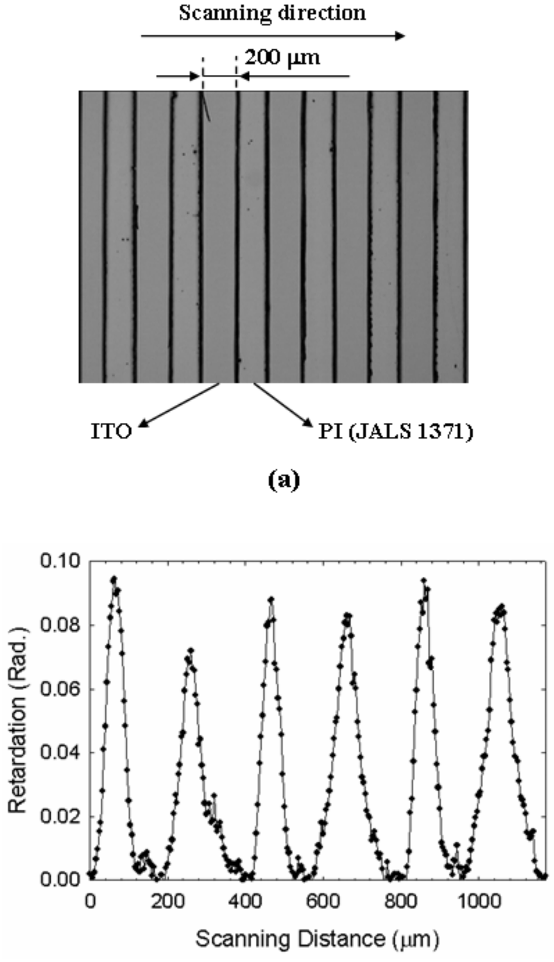
(RN1199, Nissan Chemical Industries). The wetting properties of AL1H659 on ITO or RN1199 were better than that on the mold surface. Therefore, AL1H659 is very suitable for patterning homeotropic LC anchoring on the bare ITO substrate (random planar anchoring) or the rubbed polyimide (PI) layer of RN1199 (homogeneously planar anchoring) in our micro-contact printing method.

By selecting a homogeneous alignment PI with suitable wetting differences, a homogeneously planar LC anchoring can be patterned on various types of surfaces. Fig. 3(a) shows the microscopic image of a periodic line pattern (200 μm period) with a homogeneous alignment PI (JALS 1371, JSR Co.) on the ITO substrate. The patterned surface was unidirectionally rubbed along the line direction. Therefore, birefringence was produced only in the areas with patterned PI layers due to the polymer chain ordering effect. The periodically patterned surface was probed by measuring optical retardation variation along the direction shown in Fig. 3 (a). Fig. 3(b) shows the optical retardation variation as a function of a scanning distance, where the polarization direction of the focused probing beam was 45^{o} with respect to the scanning direction. Since the spot size of focused probing beam on the measurement surface was about 100 μm, there is spatial averaging effect in our birefringence measurement. However, the periodicity of the retardation was identical to that of the mold structure.

3. Multi-Domain LC Structure by Patterned Alignment Layers

Fig. 4 (a) shows the microscopic image of the patterned homeotropic alignment layer (AL1H659) on the ITO substrate. Figs. 4 (b) and (c) are LC textures aligned by the patterned substrate and the other substrate spin-coated by AL1H659. In Figs. 4(b) and (c), the areas patterned by the homeotropic PI and the ITO areas between the patterned regions are obviously distinguished. Since the ITO areas between the PI patterns could not provide stable LC alignment condition, there were several disclination lines in Fig. 4 (b). However, LC molecules in the patterned areas were uniformly aligned with homeotropic configuration since AL1H659 on the SU-8 mold structure could be transferred to the ITO substrate due to wetting difference of AL1H659 between the mold surface and the base substrate as shown in Fig. 2.

Our micro-contact printing method can be applied to the other polymer surface to spatially modify LC orientation. In order to obtain a multi-domain LC structure with different surface tilt conditions, we patterned the commercially available homeotropic alignment agent (AL1H659) on the homogeneous alignment layer (RN1199) with a check-patterned mold (100 μm period). The baking conditions of the patterning material, AL1H659 were pre-baking at 100 ^{o}C and hard-baking at 150 ^{o}C. During transferring the homeotropic alignment layer on the homogeneous alignment layer with pre-baking of the patterning material, the contact between the substrate with the base film and the mold substrate was sustained for 20 min as shown in Fig. 1. Then, the mold substrate was removed and the substrate with the patterned alignment layer was cured at hard-baking temperature for 1 h. From the microscopic image of Fig. 5 (a), we observed the effect of squeezing out the patterning materials during contact process at the pattern edges. The optimization of baking temperature condition is under exploring for obtaining a uniform pattern.



(a)

(b)

Figure 3. Periodic line pattern of a homogeneous alignment layer (JALS 1371) on the ITO substrate : (a) microscopic image of the patterned PI layer where the rubbing direction is parallel to the line patterns and (b) birefringence variation of the patterned surface where the polarization of the probing light is 45^{o} with respect to the scanning direction.

In the final step of Fig. 1, the schematic diagram of LC alignment in our multi-domain cell structure is demonstrated. As shown in Fig. 1, we adopted a homeotropic anchoring on the other substrate.

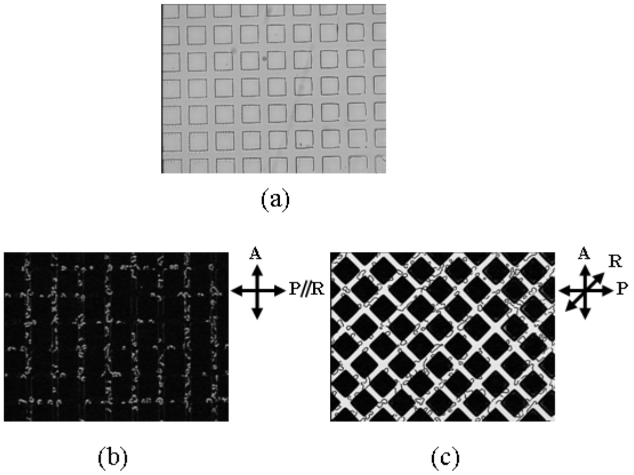


Figure 4. (a) Microscopic image of the patterned homeotropic alignment layer on the ITO substrate, (b) and (c) are the polarizing microscopic images of the LC textures when the rubbing directions of the patterned substrate are parallel and 45^o-rotated with respect to the polarizer axis, respectively.

With this cell structure, the different LC anchoring effect at two domains can be obviously observed by filling a nematic LC with a positive dielectric anisotropy at applied voltages. Figs. 5 (b) − (e) show the polarizing microscopic images of our cell. In our cell structure, there were two LC domains with homeotropic (H) and hybrid (HB) configurations as shown in Fig. 5. In the field on state, the transmittance of the only HB region was electrically controlled due to positive dielectric anisotropy of LCs used in our experiment. The texture of the HB region was uniformly changed without any defect structure and that of the H region did not show any light leakage in the patterned regions irrespective of applied voltages. The above results showed that the homeotropic alignment material was transferred precisely on the base substrate with homogeneous alignment layer.

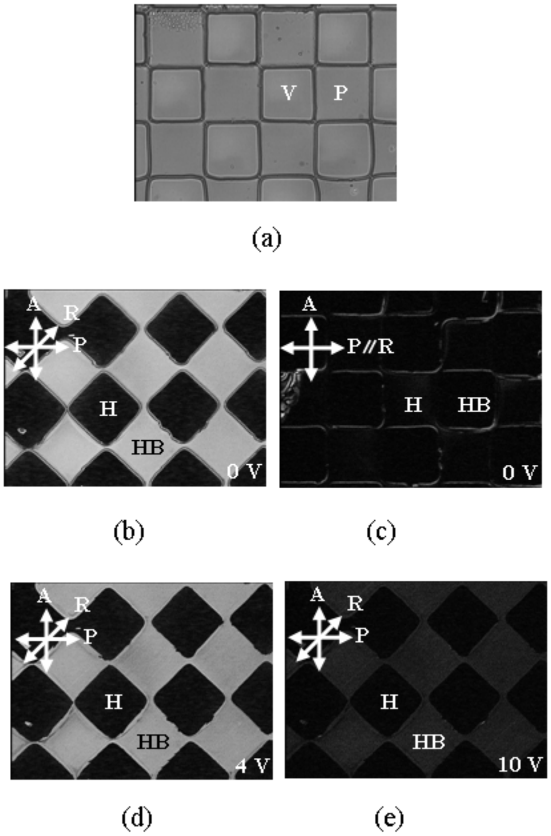


Figure 5. (a) Microscopic image of the patterned substrate where the areas of the homogeneous alignment surface and the homeotropic alignment surface are represented by the marks P and V, respectively. (b)-(e) are polarizing microscopic images of the LC cell where the two domains are aligned in a homeotropic (H) and a hybrid (HB) geometries. (b) and (c) are obtained in an absence of an applied voltage. (d) and (e) are obtained in applied voltages of 4 V and 10 V, respectively.

4. Conclusion

We have proposed a patterning method for generating multi-domain structure which could be realized with conventional LC alignment materials. By controlling temperature during imprinting procedures and facilitating wetting difference of a patterning material between the mold surface and the base surface, we could obtain uniformly and precisely patterned alignment layers in a scale from tens of micrometers to hundreds of micrometers. The development of multi-domain twisted nematic LC mode with the proposed method in now on the progress.

5. Acknowledgements

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