P-138: Axially Symmetric Domain Formed by Soft-Lithographically Patterned LC Alignment Layers

Hak-Rin Kim[1], Min-Soo Shin[2], Kwang-Soo Bae[2], June-Yong Song[3], Jong Sun Choi[4], and Jae-Hoon Kim*[2,3]

[1] School of Electrical Engineering and Computer Science, Kyungpook National University, Daegu 702-701, Korea

[2] Department of Information Display Engineering, Hanyang University, Seoul 133-791, Korea

[3] Department of Electronics and Computer Engineering, Hanyang University, Seoul 133-791, Korea

[4] School of Electronics and Electrical Engineering, Hongik University, Seoul, 121-791, Korea

Abstract
We demonstrated an axially symmetric multi-domain liquid crystal (LC) structure formed by soft-lithographically patterned LC alignment layers. In our structure, homeotropic LC alignment layers are periodically patterned on a unidirectionally rubbed homogeneous LC alignment layer. The field-induced LC reorientation on the non-rubbed patterned surfaces is determined by the easy axis of the pattern boundaries, producing axially symmetric multi-domains or a mono-domain LC structures.

1. Introduction
Recently, several types of fabrication methods for obtaining multi-domain liquid crystal (LC) structures have been proposed to enhance or modify electro-optic (EO) properties of LC-based devices. Especially, in display applications, conventional viewing angle problems, originating from the optical anisotropy of LC molecules, can be solved by introducing multi-domain structures in LC alignment through diversifying the optic axes of the LC layer in an azimuth angle [1, 2]. Among the multi-domain structures, an axially symmetric multi-domain LC structures exhibits the most ideal viewing angle characteristics due to their equally distributed optic axes in azimuth plane [3-5]. To produce the axially symmetric LC distributions, previous approaches required protrusions on the LC alignment surfaces fabricated by complex photo-lithographic process, axially symmetric boundary walls [3] usually formed by phase separation from LC/prepolymer mixtures through patterned UV exposures, or patterned electrode structures to produce symmetric field distributions [4].

In this work, we demonstrate an axially symmetric multi-domain LC structure, in the filed-on state, formed by patterned LC alignment layers. In our structure, a homeotropic LC alignment layer is periodically patterned on a homogeneous LC alignment layer. Depending on the rubbing directions on the homogeneous LC alignment layers in pixel boundaries, the filed-induced LC reorientations of the vertically aligned (VA) LC molecules on the patterned pixel areas are controlled by the pre-transition effects of the LC molecules on the pixel boundaries.

2. Experiment
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 layer is uniformly spin-coated on an ITO glass substrate. After curing the PI, the homogeneous LC alignment PI surface is unidirectionally rubbed to produce surface pretilt in LC anchoring

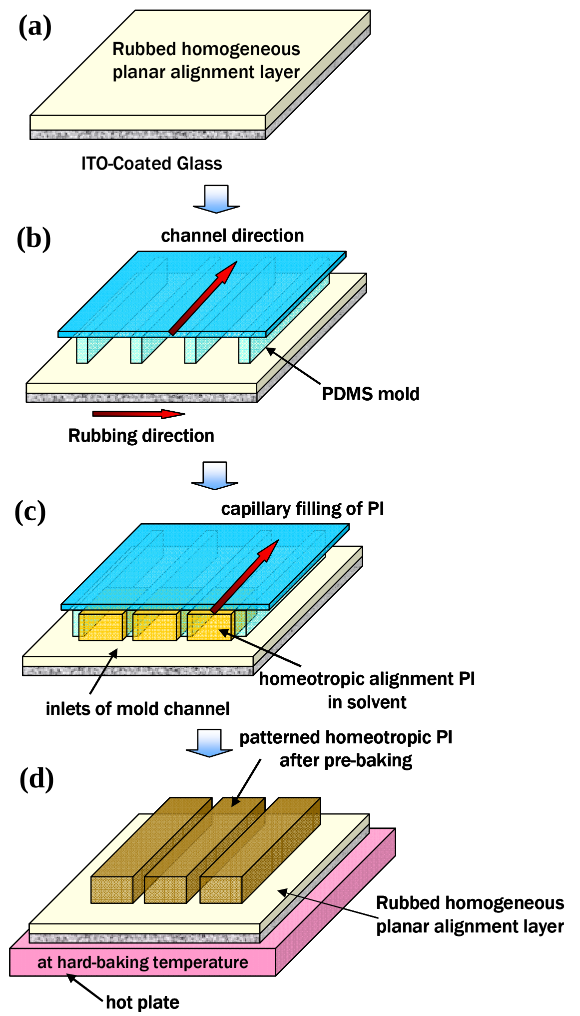

Figure 1. The schematic diagram of patterning LC alignment layer by the MIMIC method, where the homeotropic LC alignment PI is patterned on the rubbed homogeneous LC alignment PI layer : (a) a rubbed homogeneous planar LC alignment PI layer on an ITO substrate, (b) placing PDMS mold structure with micro-channel on the homogeneous PI, (c) capillary filling of a homeotropic PI in solvent state, (g) final structure after hard-baking the patterned homeotropic PI layer.

ISSN/007-0966X/07/3801-0721-$1.00 © 2007 SID

(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. Since the gas from the solvent of the PI, produced during this pre-baking step, can be easily escaped by diffusing into the PDMS, the conformal contact of the mold structure with the base PI surface can be stably preserved. Then, the mold structure is carefully removed. Due to very stable interfacial property of the PDMS, the pre-baked homeotropic PI patterns are not damaged during this step). Finally, the patterned homeotropic LC alignment PI layer is fully cured at hard-baking temperature, which is not rubbed (Fig. 1(d)). Therefore, the LC alignment layers patterned by MIMIC method do not have pretilt in LC anchoring in itself.

Figures 2(a) and 2(b) show the SEM images of the patterned PI substrate in different magnification, where we can see a uniform homeotropic PI patterns of about 1 μm thick on the homogeneous PI layer. The width and the spacing of the homeotropic LC alignment PI line patterns are 100 μm and 30 μm, respectively. In preparing our patterned LC alignment surface, the MIMIC method has an advantage in that the easy axis of the base PI layer can be pre-determined before stacking the upper PI layer. Its simplicity in fabrication and its superior fidelity in pattern-transferring from the mold are also important reasons to be chosen as our patterning method in this experiment.

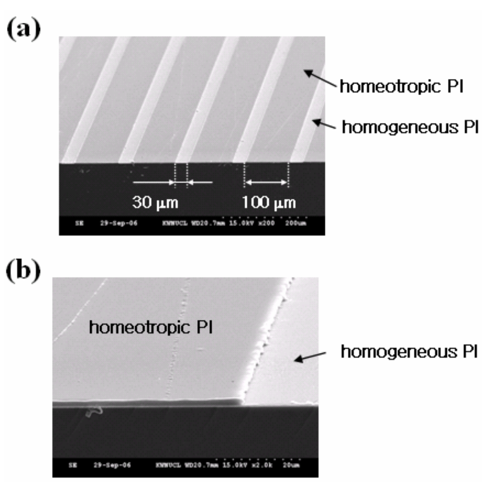

Figure 2. SEM images of the patterned PI layers, where a homeotropic LC alignment PI is patterned in periodic lines on a rubbed homogeneous LC alignment PI layer.

3. Result and Discussion

To examine the controllability of the field-induced LC reorientation by the patterned surface effects, the patterned substrate (Fig. 1 (d)) was assembled with an ITO substrate coated by a non-rubbed homeotropic LC alignment PI layer. As a nematic LC (NLC), MLC6610 (E. Merck) with a negative dielectric anisotropy was filled

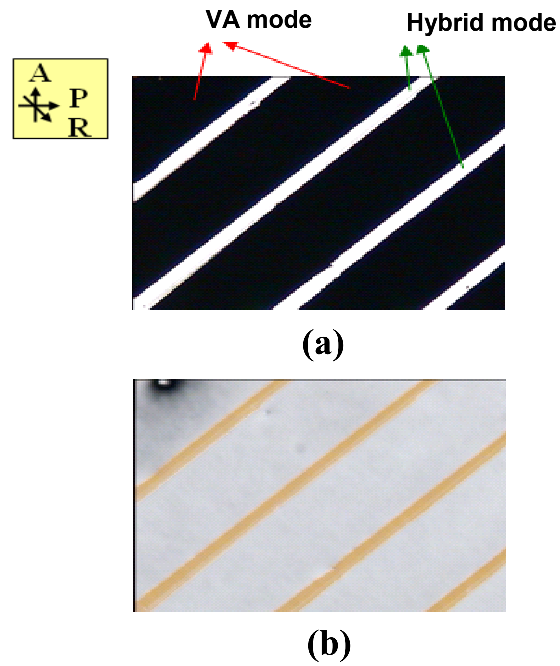

Figure 3. The polarizing microscopic images of the LC ($\Delta\varepsilon$<0) textures at applied voltages of (a) 0 V and (b) 4 V, where the LCs are aligned between a patterned PI layer, shown in Fig. 1, and a non-rubbed homeotropic PI layer. A and P denote the transmission axes of the polarizers and R denotes the rubbing direction of the homogeneous alignment PI of the patterned PI layers.

into the cavity by capillary effect in an isotropic temperature. Figure 3 (a) shows the polarizing microscopic image of the LC texture at field-off state.

On the patterned homeotropic PI surface, the LCs were aligned with the VA mode without pretilt and the texture exhibited dark state. On the rubbed homogeneous PI surface, the LCs were aligned with the hybrid mode with pretilt and the texture exhibited bright state due to retardation.of the LC layer At filed-on states, the LC molecules between the homeotropic LC anchoring surfaces were uniformly reoriented without generating Schlieren textures, as shown in Figs. 3 (b) although there was no pretilt condition on those surfaces. Such uniform reorientation can be explained by LC-LC interaction on the pattern edges. The tilting direction of the hybrid mode structure was predetermined by the rubbing direction of the homogeneous PI layer and the field-induced LC reorientation took place before the Frederick transition of the LC molecules in the VA region [5]. Therefore, the tilting direction of the LC molecules with initially VA mode was also determined by elastic LC-LC interaction. Such behavior could be observed obviously by applying low frequency (0.5 Hz) triangle wave to the cell, where the field induced LC reorientation took place from the pattern edges and propagated to the central regions of the patterns. This meant that the field-induced tilting direction was controlled by the tilting direction of the pattern edges with the hybrid mode via lateral domain propagation.

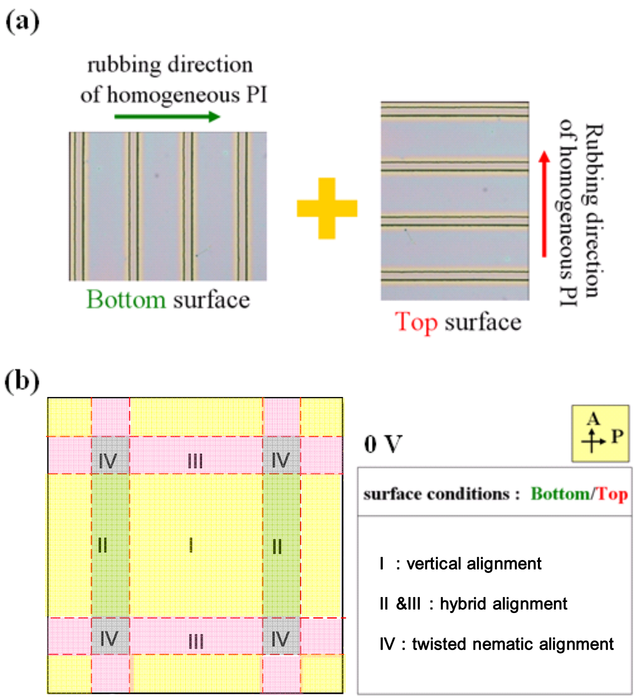

Figure 4. (a) Schematic diagram showing cell assembly for axially symmetric LC domain generation by a pair of patterned alignment layers. (b) Schematic diagram of four domains

With these features, we generated axially symmetric LC ($\Delta\varepsilon<0$) domains in field-on state by assembling a pair of the identically patterned substrates, orthogonally to each other in terms of the rubbing direction of the homogeneous PI layer as

shown in Fig. 4 (a). In this case, we can produce four domains in the absence of applied voltage as shown in Fig. 4 (b). In the pixel areas (region I), the NLC is vertically aligned without pretilt. At side of the pixels (regions II & III), the NLC is aligned with hybrid structures. Among them, the pretilt of two hybrid LC domains (region II) is determined by the rubbed homogeneous LC alignment layer of the bottom substrate and the pretilt of the others (region III) is determined by the rubbed homogeneous LC alignment layer of the top substrate. Therefore, there are two types of pretilt directions in four hybrid-aligned regions and the directions are orthogonal to each other. At corners, twisted nematic structures are identically formed. In this structure, the filed-induced LC reorientation in the pixel area is determined by the pretilt direction of the boundary LC molecules aligned with hybrid configuration.

Figure 5 shows the polarizing microscopic images of the LC texture under applied voltages. Without applied voltage, we can get dark state in region I as shown in Fig 5(a). If we apply 10V, each pixel area has four dark brushes, which means that LCs are aligned in a direction parallel to one of polarizers. As shown in the dark brushes, the effect of the patterned hybrid regions on the field-induced LC reorientation is the strongest along the lines bisecting the pixel areas. The field-induced tilting directions in the area of between two bisecting lines are determined via competition of the orthogonal boundary effect. In these areas, the LCs are aligned by 45^{o} with respect to the direction of the polarizers, where the effect of the pixel boundaries are ideally equal. Such behavior was confirmed by 3-D simulation of LC distribution. The domain propagation from the pixel boundaries generates axially symmetric multi-domain structure. The axially symmetric distribution is very useful in enhancing viewing angle properties in LCDs.

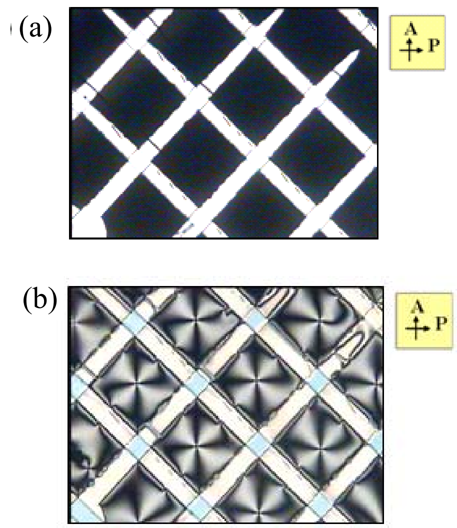

Figure 5. The polarizing microscopic images of the LC textures at applied voltages of (a) 0V and (b) 10V when the rubbing direction is rotated by 45^{o} with respect to one of polarizers.

4. Conclusion

We demonstrated the axially symmetric multi-domain liquid crystal (LC) structure formed by patterned LC alignment layers. In our structure, a non-rubbed homeotropic LC alignment layer was periodically patterned on a rubbed homogeneous LC alignment layer. The patterned homeotropic LC alignment layer was simply fabricated on the homogeneous LC alignment base layer by MIMIC with the patterned elastomeric mold structure. When the patterned substrate was assembled with the non-rubbed homeotropic LC alignment PI layer, the LC molecules with VA mode were unifromly reoriented at applied voltages although there was no pretilt condition on both layers due to tilting propagation from the pretilted LC molecules in pixel boudaries with the hybrid mode. Especially, when we assembled two patterned substrates orthogoanlly to each other. The orthogonal boudary effect produced the axially symmetric LC distribution in the pixel areas at applied voltages.

5. Acknowledgements

This research was supported by Samsung a grant (F0004052) from Information Display R&D center, one of the 21st century Frontier R&D program funded by the Ministry of Commerce, Industry and Energy of Korean government.

6. References

[1] S. Varghese, G. P. Crawford, C. W. M. Bastiaansen, D. K. G. de Boer, and D. J. Broer, "Four-domain twisted vertically aligned liquid crystal pixels using microrubbing", Appl. Phys. Lett., Vol. **86**, pp. 181914, 2005.

[2] S. Varghese, S. Narayanankutty, C. W. M. Bastiaansen, G. P. Crawford, and D. J. Broer, "Patterned Alignment of Liquid Crystals by □-rubbing", Adv. Mater., Vol. **16**, pp. 1600-1605, 2004.

[3] S. H. Lee, S. H. Park, M.-H. Lee, S. T. Oh, and G.-D. Lee, "Homeotropically aligned nematic liquid crystal device locked by a polymer wall with wide viewing angle", Appl. Phys. Lett., Vol. **86**, pp. 031108, 2005.

[4] S. H. Lee, H. Y. Kim, Y. H. Lee, I. C. Park, B. G. Rho, H. G. Galabova, and D. W. Allender, "Wide viewing angle, homeotropic nematic liquid-crystal display controlled by effective field", Appl. Phys. Lett., Vol. **73**, pp. 470-472, 2005.

[5] C. Nieuwkerk, M. van Deurzen, "Multi-domain Vertically Aligned Nematic LCDs with Siwtchable Pixel Walls", SID Symposium Digest, Vol. **36**, pp.1168-1171, 2005.

[6] Y. Xia and G. M. Whitesides, "Soft Lithography", Angew. Chem., Int. Ed. Vol. **37**, pp. 550-575, 1998.