Journal of Information Display
Vol. 12, No. 4, December 2011, 191–194

Symmetric-viewing liquid crystal display with alternating alignment layers in an inverse-twisted-nematic configuration

Jun-Hee Na, Hongmei Li, Seung Chul Park, and Sin-Doo Lee*

School of Electrical Engineering #032, Seoul National University, Kwanak, P.O. Box 34, Seoul 151-600, South Korea

(*Received 7 July 2011; Revised 23 July 2011; Accepted 2 August 2011*)

A symmetric-viewing inverse-twisted-nematic (ITN) liquid crystal display (LCD) with alternating alignment layers was developed using a stamping-assisted rubbing (SAR) technique. A patterned layer of a fluorinated acrylate polymer was transferred onto the first rubbed vertical-alignment layer prepared on a substrate by stamping. The fluorinated acrylate polymer provided a protective layer covering the first rubbed alignment layer during the second rubbing process, which promoted the vertical alignment of the LC molecules. The LC cell in the ITN geometry with two orthogonally rubbed alignment layers showed symmetric-viewing characteristics with fourfold symmetry. The SAR technique was shown to be a mask-free alignment method of producing multidomains for symmetric-viewing LCDs.

Keywords: stamping-assisted rubbing; symmetric viewing; inverse twisted nematic; multidomains; fourfold symmetry

1. Introduction

Liquid crystal displays (LCDs) based on the twisted-nematic (TN) mode have been widely used for flat panels in portable TVs and laptop computers due to their relatively simple and cost-effective manufacturing. The conventional TN mode resulting from the positive dielectric coupling of a nematic LC (NLC), however, has several disadvantages such as a limited contrast ratio, wavelength dependence, and narrow viewing characteristics. It is known that an inverse TN (ITN) mode [1,2] shows high contrast because of the complete extinction under crossed polarizers, giving a dark state, in the initial homeotropic alignment of the LC molecules. Moreover, the ITN mode exhibits wavelength independence in the white state, but still suffers from asymmetric-viewing properties. Therefore, a new symmetric-viewing technology applicable for the ITN mode needs to be developed for high-performance LCDs.

In this work, a stamping-assisted rubbing (SAR) method [3,4] of producing alternating alignment layers for a symmetric-viewing ITN-LCD with multidomains was developed. A patterned protective layer of a fluorinated acrylate polymer was transferred onto the first rubbed alignment layer prepared on a substrate by stamping. The fluorinated acrylate polymer covered the first alignment layer during the second rubbing process, which promoted the vertical alignment of the LC molecules. The regions covered with the patterns of the protective polymer layer preserved the initial alignment generated through the first rubbing process. As shown in Figure 1, the LC cell was assembled such that the rubbing directions on the two substrates were perpendicular to each other, so that four different ITN domains corresponding to two clockwise and two counterclockwise directions were produced. Both splay and twist deformations were involved in the four domains (4Ds). As a consequence, the twist directors of two adjacent domains were different from each other [5].

The basic structure and operation principles of the developed 4D ITN-LC cell are shown in Figure 1. The inner surfaces of the two substrates were treated to promote the initially homeotropic alignment of the LC molecules [6]. An NLC material with a negative dielectric anisotropy was placed between the two rubbed substrates. Note that a certain amount of molecular chirality was introduced to generate a desirable amount of natural twist in the presence of an applied voltage (V). In the dark state, the homeotropically aligned NLC cell blocked the incident light under crossed polarizers. When a voltage above the Fredericks threshold (V_{th}) was applied, the LC molecules tended to orient along the direction perpendicular to the applied electric field, and twist distortions of the LC occurred in an activated bright state along different directions in the alternating rubbed domains. For $V > V_{\text{th}}$, the incident light passed through the crossed polarizers, and the resultant light transmission varied with the magnitude of the applied voltage. The directions of the LC molecules in the dark and bright states are schematically shown in Figure 1(c) and (d), respectively.

*Corresponding author. Email: sidlee@plaza.snu.ac.kr

ISSN 1598-0316 print/ISSN 2158-1606 online

http://dx.doi.org/10.1080/15980316.2011.621316
http://www.tandfonline.com

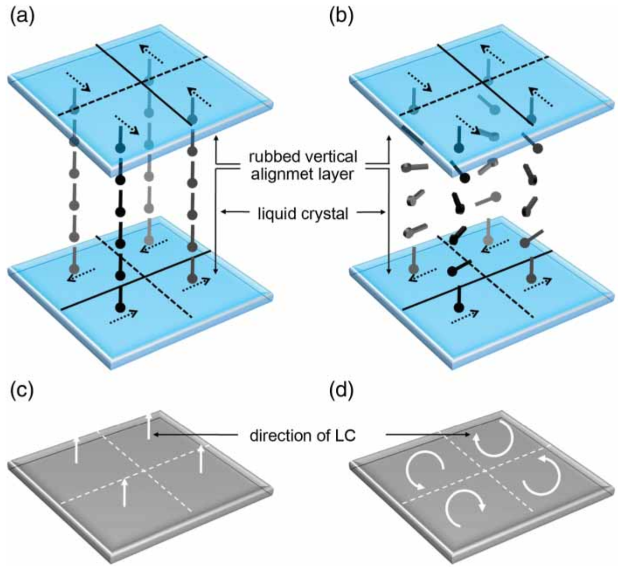

Figure 1. Schematic diagram and operation principle of the 4D ITN-LC cell: the alternating rubbing directions and the LC alignment (a) under no applied voltage (a dark state) and (b) in the presence of an applied voltage (a bright state) and the directions of the LC molecules (c) in the dark state and (d) in the bright state.

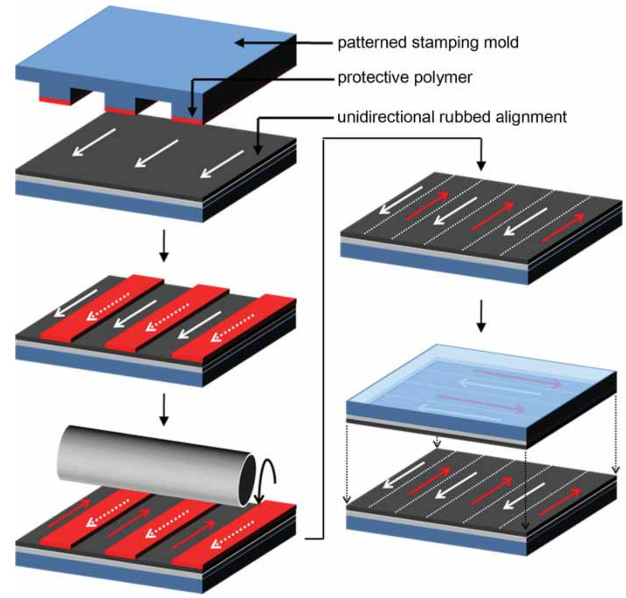

Figure 2. SAR technique for achieving the alternating alignment of LC: a stamping process involving transferring the protective layer of a fluorinated acrylate polymer onto the first rubbed alignment layer, the substrate with the protective layer on top of the first alignment layer, the second rubbing process on the first alignment regions that are not covered with the protective layer, the fabricated bidirectional alignment layer, and two substrates assembled such that the rubbing directions are perpendicular to each other.

2. Experimental considerations

The SAR method of producing alternating alignment is shown in Figure 2. The vertical-alignment layer of polyimide (PI) (AL60702, Japan Synthetic Rubber) was first spin-coated onto a substrate and then rubbed unidirectionally to promote the vertical alignment with a uniform pre-tilt of the LC molecules. For the second rubbing process along the direction opposite to the first rubbing direction, a protective layer (Novec EGC-1700, Sumitomo 3M) prepared on a patterned stamping mold of poly(dimethylsiloxane) (PDMS, GE silicones) was transferred onto the first rubbed PI by stamping and was subsequently cured at room temperature. Note that EGC-1700, a fluorinated acrylate polymer dissolved in a hydrofluoroether solvent, did not chemically affect the alignment layer. The second rubbing process was then performed on the regions that were not covered with the protective layer along the direction opposite to the first rubbing direction. The substrate was rubbed five times to ensure the saturation of the tilt bias angle [7]. The protective layer was finally dissolved in the hydroflouroether solvent (Novec HFE-7100, Sumitomo 3M), and alternating alignment was readily achieved. For the fabrication of the ITN-LC cell, two substrates with an alternating alignment layer were assembled such that the rubbing directions on the two substrates were perpendicular to each other. The cell thickness was maintained using 5 μm thick glass spacers. The LC (MLC-6608, Merck Ltd) with a negative dielectric anisotropy was injected into the cell by capillary action at room temperature. The birefringence and the dielectric anisotropy of MLC-6608 were $\Delta n = 0.083$ and $\Delta\varepsilon = -4.2$, respectively. A square-wave voltage at a frequency of 1 kHz was applied to the ITN-LC cell to measure the electrooptical (EO) transmission and the response times. The measurements were carried out using a digitizing oscilloscope (WaveRunner 6030, Lecory) and a light source of a He–Ne laser with the wavelength of 632.8 nm at room temperature.

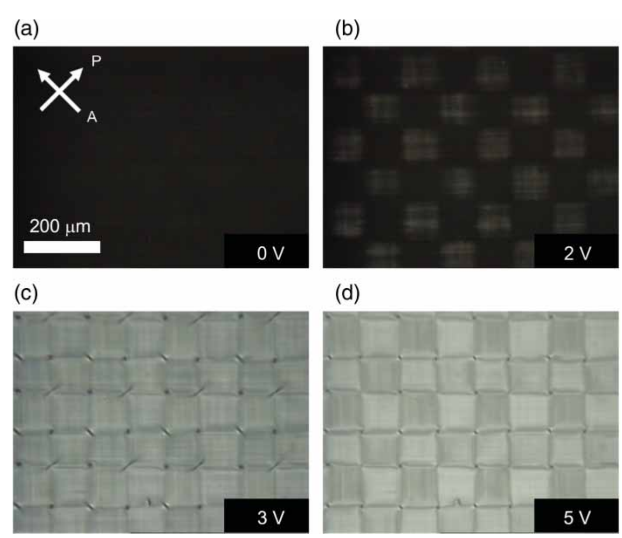

Figure 3. Microscopic textures of the 4D ITN-LC cell with two alternating alignment layers observed under crossed polarizers at different voltages: (a) 0 V; (b) 2 V; (c) 3 V; and (d) 5 V.

3. Results and discussion

The microscopic textures of the ITN-LC cell with 4Ds due to the alternating alignment in Figure 3 were observed with a polarizing optical microscope (Optiphot2-pol, Nikon) under crossed polarizers at different applied voltages. In the absence of an applied voltage, the LC molecules were vertically aligned, as shown in Figure 1(a). Thus, under crossed polarizers, no light propagated, and a completely dark state was obtained, as shown in Figure 3(a). At 2 V, which was above V_{th}, the transmission slightly increased, as shown in Figure 3(b). At 3 V, the LC molecules were partially twisted, and the transmission further increased, as shown in Figure 3(c). At a relatively high voltage of 5 V, the LC molecules were mostly twisted in the plane of the substrate, and a bright state was obtained, as shown in Figure 3(d). It should be noted that four disclination lines enclosing each square pattern separated the four different domains. The adjacent domains were the oppositely twisted domains. This can be well understood from Figure 1(d). The small difference in brightness observed in Figure 3(d) indicates that the first and second rubbing processes were not identical. Due to the physicochemical nature of the PI that was used, the LC alignment after the first rubbing seemed dominant over that after the second rubbing. Meanwhile, as the thickness of the fluorinated acrylate polymer was at most 100 nm (much less than the cell thickness of 5 μm and the wavelength of visual light, typically 500 nm), it is negligible for the brightness difference arising from the cell thickness difference. As a consequence, a difference in brightness was observed. Moreover, non-uniformity in a single domain often appeared.

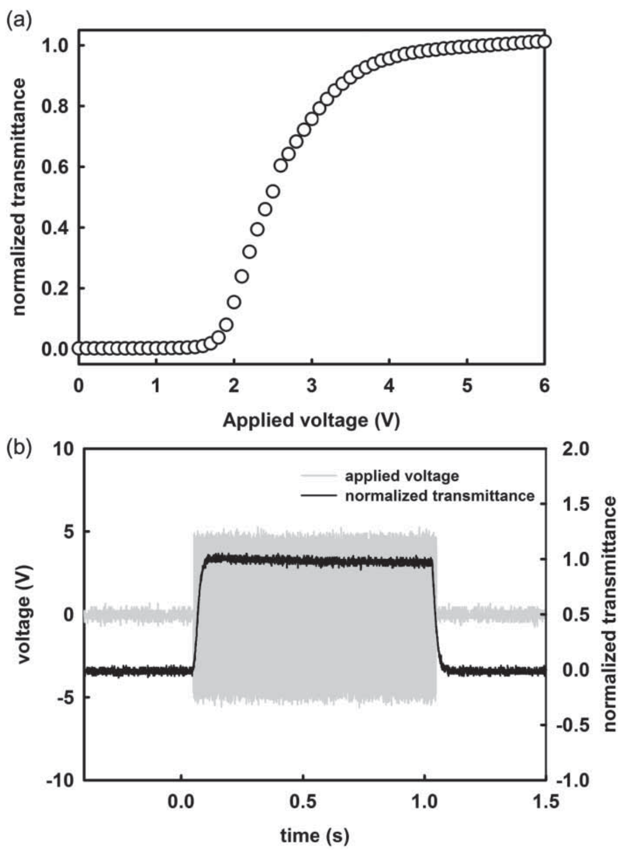

Figure 4. EO characteristics of the 4D ITN-LC cell: (a) EO transmittance and (b) dynamic response as a function of the applied voltage in the square-wave form. The rising and falling times ($\tau_{\text{r}} = 28$ ms and $\tau_{\text{f}} = 25$ ms) were measured at 4 V. The dark and gray curves represent the dynamic response and the applied voltage, respectively.

Figure 4 shows the normalized EO transmission and the dynamic response of the 4D ITN-LC cell in the presence of a bipolar voltage in a square-wave form at 1 kHz. The EO properties were measured as a function of the applied voltage under crossed polarizers. Irrespective of the small difference in brightness among the 4Ds, as shown in Figure 4(a), the EO curve shows continuous gray scales, and the contrast ratio was found to be about 50:1. In Figure 4(b), the black and gray curves represent the EO response of the ITN-LC cell and the applied voltage, respectively. It was found that the rising time was $\tau_r = 28 \pm 2$ ms and that the falling time was $\tau_f = 25 \pm 2$ ms at an applied

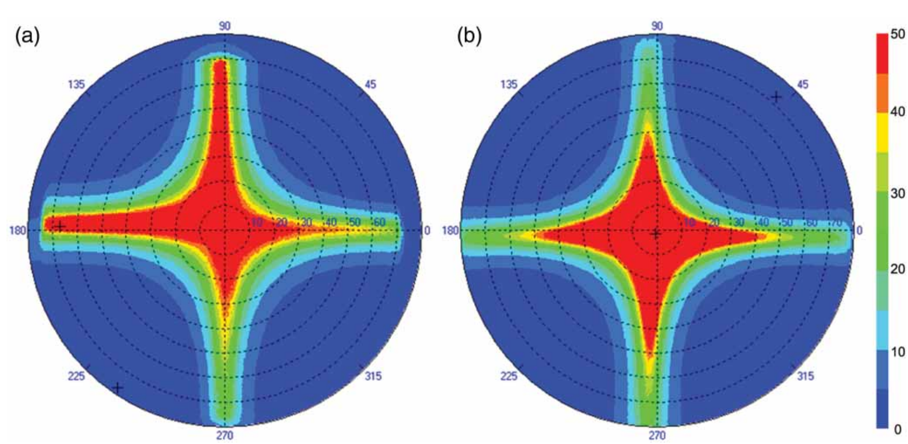

Figure 5. Iso-contrast contours: (a) a conventional ITN-LC cell and (b) the 4D ITN-LC cell with two alternating alignment layers.

voltage of 4 V, without any driving compensation. This switching speed range will be further improved using a fast-response LC material for high-speed applications.

The viewing angle characteristics of the ITN-LC cell, measured at 4 V using a spatial photometer (EZ contrast 160R, ELDIM), are shown in Figure 5. A conventional ITN-LC cell with a single domain exhibits asymmetric and relatively narrow viewing properties, as shown in Figure 5(a). In contrast, the 4D ITN cell without any compensation film showed quite symmetric-viewing properties with respect to the axes of the polarizers in the vertical and horizontal directions. This is attributed to the optical compensation among the four differently twisted domains produced by the alternating alignment in the ITN geometry, as shown in Figure 1(d).

4. Conclusion

Demonstrated herein was a symmetric-viewing ITN-LCD with 4Ds due to two alternating alignment layers produced via SAR. With the help of an inert protective layer of a fluorinated acrylate polymer, the second rubbing process was successfully employed without causing any mechanical and chemical damage to the first rubbed alignment layer. The ITN-LC cell with 4Ds presented here showed continuous gray scales with good linearity as well as the symmetric-viewing characteristics that are needed for high image quality. The SAR approach is basically mask-free and has a potential for the simple and cost-effective fabrication of large ITN-LCDs.

Acknowledgement

This work was supported in part by Samsung Mobile Display Co., Ltd and Interuniversity Semiconductor Research Center (ISRC).

References

[1] S.-W. Suh, S.T. Shin, and S.-D. Lee, Mol. Cryst. Liq. Cryst. **302**, 163 (1997).
[2] S.-W. Suh, S.T. Shin, and S.-D. Lee, Appl. Phys. Lett. **68**, 2819 (1996).
[3] W. Choi, M.-H. Kim, Y.-J. Na, K. Koo, and S.-D. Lee, IMID'09 Dig. 755 (2009).
[4] K. Koo, J.-H. Na, Y.-T. Kim, H. Li, and S.-D. Lee, J. Inf. Display **10**, 180 (2009).
[5] M. Schadt, H. Seiberle, and A. Schuster, Nature **381**, 212 (1996).
[6] J. Cognard, *Alignment of Nematic Liquid Crystals and Their Mixtures* (Gordon and Breach, London, 1982).
[7] M.E. Becker, R.A. Kilian, B. Kosmowski, and D.A. Mlynski, Mol. Cryst. Liq. Cryst. **132**, 167 (1986).