Journal of Information Display, Vol. 10, No. 2, June 2009 (ISSN 1598-0316)

Fabrication of a Dual-Gap Substrate Using the Replica-molding Technique for Transflective Liquid Crystal Displays

Yeun-Tae Kim[**], **Jong-Ho Hong**[**], **Seong-Min Cho**[**], **and Sin-Doo Lee**[*]

Abstract

A replica-molding method of fabricating a dual-gap substrate for transflective liquid crystal (LC) displays is demonstrated. The dual-gap substrate provides homeotropic alignment for the LC molecules without any surface treatment and embedded bilevel microstructure on one of the two surfaces to maintain different cell gaps between the transmissive and reflective subpixels. The proposed transflective LC cell shows no electro-optic disparity between two subpixels and reduces the panel thickness and weight by 30% compared to the conventional transflective LC cell, which has two glass substrates.

Keywords: Transflective liquid crystal display, dual-gap substrate, polydimethylsiloxane, replica-molding technique

1. Introduction

Transflective liquid crystal displays (LCDs) are widely used in portable devices such as cellular phones, personal digital assistants, and the recent netbook computers because of their low power consumption, good readability both indoors and outdoors, and high portability. Generally, an individual pixel of a transflective LCD is separated into two subpixels: the transmissive (T) and reflective (R) regions. The two regions are used for transmitting light from the backlight unit, and for reflecting the ambient light, respectively. To compensate for the optical-path difference (OPD) between regions T and R, several LC modes, including an electrically controllable birefringence mode [1], a vertical aligned mode [2], a hybrid aligned nematic mode [3], an in-plane switching mode [4], and a fringe-field switching mode [5], have been proposed in either a single- or a dual-gap configuration. The dual-gap configuration is used in most cases since it provides maximum light efficiency and has a simple optical structure. It suffers, however, from high fabrication cost and low yield for the compensation of the OPD between the two subpixels. Furthermore, two driving schemes are required for regions T and R due to the disparity between the electro-optic (EO) properties of the two subpixels. Therefore, a new approach to a simple and cost-effective process must be developed for practical applications.

In this work, a replica-molding technique for fabricating a dual-gap substrate for a transflective LCD is demonstrated. The dual-gap substrate, used as a top substrate in the proposed transflective LC cell, provides bilevel microstructures on one of the two surfaces to maintain two different cell gaps in regions T and R, and allows for a spontaneously vertical alignment. The proposed transflective LC cell shows no EO disparity between regions T and R and reduces the volume and weight by about 30% compared to the conventional transflective LCD with two glass substrates.

2. Construction of a Transflective LCD with a Dual-Gap Substrate

A replica-molding technique that can easily duplicate information like the geometric shape stored in the master, was used to fabricate a dual-gap substrate with multifunctions. The details of the fabrication process were discussed earlier [6]. Since the polydimethylsiloxane (PDMS) surface provides a low surface energy and hydrophobicity [7], the LC alignment induced by the PDMS surface was first examined. It is known that a surface with low hydrophobicity aligns the LC vertically [8, 9]. An LC cell with two PDMS

Manuscript Received June 02, 2009; Revised June 12, 2009; Accepted for publication June 25, 2009.
This work was supported in part by Inter-University Semiconductor Research Center and the LCD Division of Samsung Electronics Co.

[*] Member, KIDS; [**] Sutdent Member, KIDS
Corresponding author : Sin-Doo Lee
School of Electrical Engineering, Seoul National University, Kwanak P.O. Box 34, Seoul 151-742, Korea
E-mail: sidlee@plaza.snu.ac.kr **Tel**: +82-2-880-1823 **Fax**: +82-2-874-9769

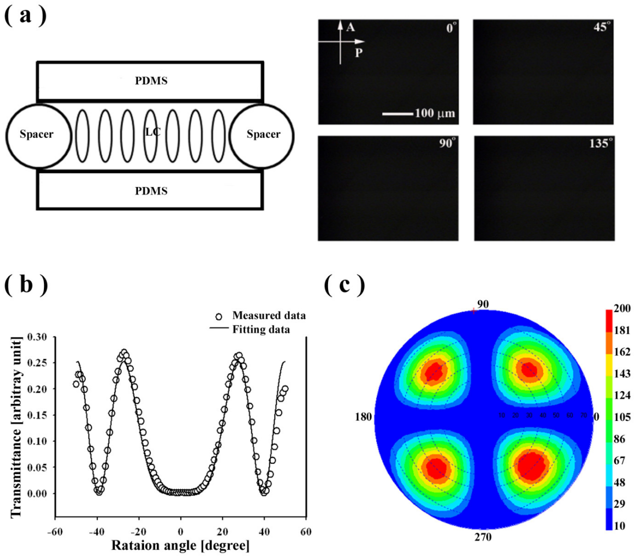

Fig. 1. The vertical alignment properties of PDMS: (a) a schematic diagram of an LC cell with PDMS substrates, along with microscopic textures; (b) the transmittance curve corresponding to each rotation angle measured through the crystal rotation method; and (c) the luminance graph in the absence of a voltage.

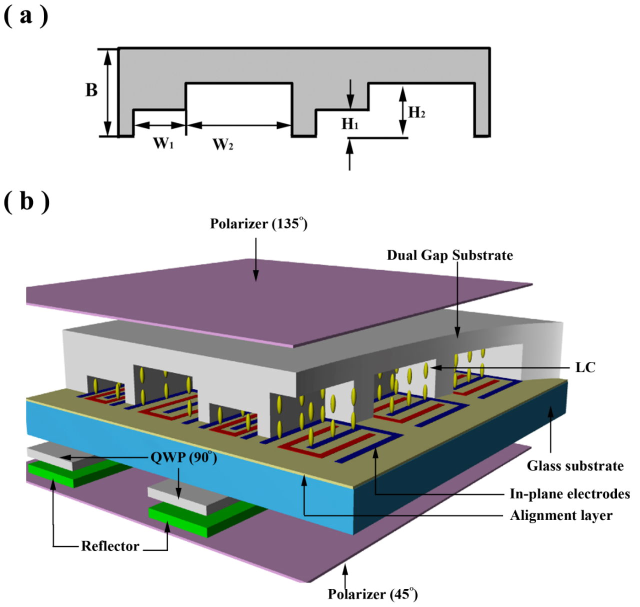

Fig. 2. The construction of the proposed transflective LC cell with a dual-gap substrate: (a) the geometric shape of the dual-gap substrate; and (b) the schematic diagram of the proposed transflective LC cell showing the crossed polarizers, QWP, reflector, and in-plane electrodes.

substrates was prepared as shown in the left diagram in Fig. 1(a). The cell thickness was maintained using a 50-μm-thick film spacer, and the LC material that was used was ZLI 2293 (Merck), whose birefringence and dielectric anisotropy are 0.1322 and 10, respectively. At the right side of Fig. 1(a), microscopic textures observed with a polarizing optical microscope (Optiphot2-pol, Nikon) under crossed polarizers are shown. A dark state was always produced irrespective of the rotation of the LC cell between the crossed polarizers, indicating that the LC molecules were vertically aligned. To estimate the pretilt angle of the LC on the PDMS surface, the transmittance was measured, using the crystal rotation method [10], as a function of the rotation angle, as shown in Fig. 1(b). It was found that the pretilt angle of 89.7° was obtained using the center angle of -1.5° in the symmetric transmittance curve in Fig. 1(b). Fig. 1(c) is the luminance graph of the LC cell, showing the typical luminance of the vertically aligned state, measured using a spatial photometer (EZ contrast 160R, ELDIM).

Fig. 2(a) shows the geometric shape of the dual-gap substrate that was used for constructing the proposed transflective LCD. The physical dimensions of W_1, W_2, H_1, H_2, and B of the dual-gap substrate were 100, 200, 20, 1.2, 2.4, and 250 μm, respectively. Fig. 2(b) shows the schematic diagram of a single-mode transflective LC cell with dual cell gaps, where one of the two substrates is a dual-gap one (the top substrate) and the other is a glass substrate with in-plane electrodes (the bottom substrate). To produce nearly identical transmission curves between regions T and R, different cell gaps and intervals of the in-plane electrodes between regions T and R were designed with the help of numerical simulation [6]. The cell gap and interval of the in-plane electrodes in region T are 2.4 and 20 μm, respectively, and 1.2 and 10 μm in region R, respectively. The proposed transflective LC cell is composed of two crossed polarizers, a quarter-wave plate (QWP), a reflector, and two vertically aligned LC layers in regions T and R. The optic axis of the QWP is at an angle of 45° to one of the two crossed polarizers. The in-plane electrodes were placed at 45° to the optic axes of the crossed polarizers, as shown in Fig. 2(b). For the vertical alignment of the LC molecules, JALS 684 (Japan Synthetic Rubber Co.) was coated on the bottom substrate with in-plane electrodes. A square-wave voltage with a frequency of 1 kHz was applied to the proposed transflective LC cell to measure the EO transmission and the response times. The measurements were carried out using a digitizing oscilloscope (TDS320, Tektronix) and a light source of a He-Ne laser with a wavelength of 632.8 nm, at room temperature.

3. Results and Discussion

We discuss the EO properties of the proposed transflective LC cell with a dual-gap substrate in the vertically aligned LC configuration. The operation principle of the proposed transflective LCD is depicted in Fig. 3. As shown in Fig. 3(a), in region T, the linearly polarized light passing through the vertically aligned LC layer experiences no phase retardation; thus, the incident light is completely blocked under the crossed polarizers in the absence of the applied voltage. In region R, the linearly polarized incident light undergoes the optical retardation of λ/2 due to the QWP and the reflector, where λ is the wavelength of the light. The outcoming light is then blocked by the front polarizer, and a dark state is obtained when no voltage is applied. Since the LC molecules in the two regions are reoriented along the in-plane electric field in the presence of an applied voltage, the phase retardation occurs in both regions T and R, as shown in Fig. 4(b). In region T, the linearly polarized incident light is transmitted through the front polarizer due to the phase retardation of the LC layer. In region R, the incident linearly polarized light undergoes optical retardation between λ/2 and 3λ/4 due to the LC layer, QWP, and reflector. As a result, a bright state in region R is produced under the applied voltage.

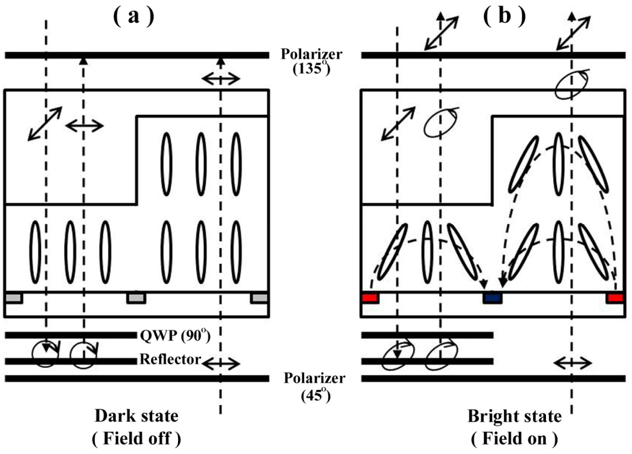

Fig. 3. The operation principle of the proposed transflective LC cell: (a) a dark state (field-off); and (b) a bright state (field-on).

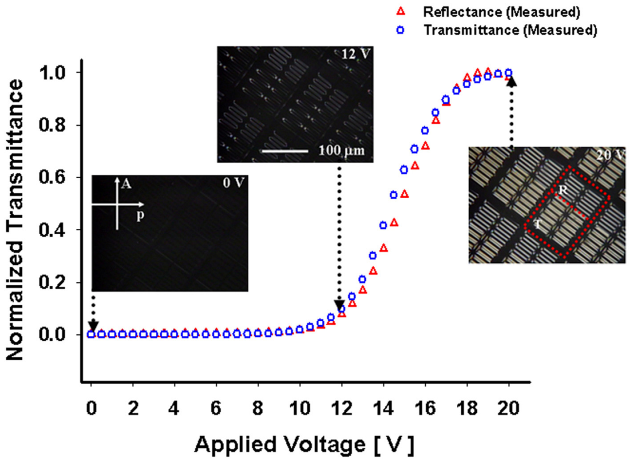

Fig. 4. The normalized transmittance and the reflectance of the proposed transflective LC cell, along with microscopic textures. Here, the open circles (blue) and the open triangles (red) denote the experimental results of the transmittance and the reflectance, respectively.

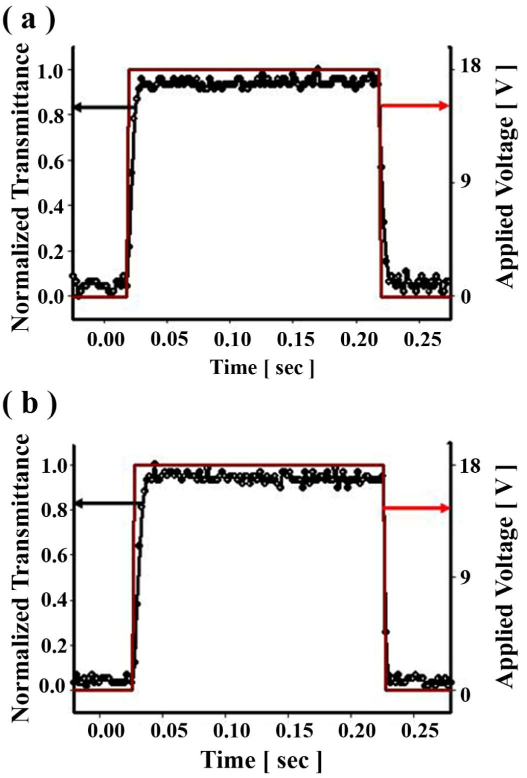

Fig. 5. The dynamic response of the proposed transflective LC cell: (a) the rising and falling times in region T; and (b) the rising and falling times in region R.

In Fig. 4, the normalized transmittance and the reflectance of the proposed transflective LC cell are shown as a function of the applied voltage, along with the microscopic textures observed with a polarizing optical microscope under the crossed polarizers. The transmittance and reflectance were normalized for the examination of the EO disparity between regions T and R. As shown in Fig. 4, the EO characteristics in regions T and R were nearly identical to each other. This allows for the use of a single driving scheme to operate the proposed transflective LCD. The microscopic textures were observed without the reflector to distinguish between regions T and R. In the absence of an applied voltage, no light was transmitted through the proposed LC cell, and a dark state was thus obtained between regions T and R. Under an applied voltage of 20 V, the LC molecules were reoriented along the in-plane electric field, and light was transmitted through the proposed LC cell due to the phase retardation through the LC layer. As shown in Fig. 4, region T was somewhat brighter than region R since the phase retardation in region T was approximately twice of that in region R at the same applied voltage.

The dynamic EO response in region T and that in region R are shown in Fig. 5(a) and (b), respectively. The rising time (from 10% to 90% transmittance) and falling time (from 90% to 10% transmittance) in region T were $\tau_{on} = 7.49$ ms and $\tau_{off} = 5.43$ ms, respectively, and in region R, $\tau_{on} = 6.67$ ms and $\tau_{off} = 3.07$ ms, respectively. Note that the measured switching times are fast enough for video rate applications.

4. Conclusions

A new type of transflective LCD using a dual-gap substrate in a vertically aligned LC configuration was presented. The dual-gap substrate fabricated using the replica-molding technique is capable of maintaining two different LC thicknesses between the two subpixels, and of spontaneously aligning the LC molecules vertically. The EO characteristics in regions T and R were found to be quite similar, making a single driving scheme applicable. The proposed approach of using a dual-gap substrate for constructing a transflective LCD presented here will provide better portability as well as a cost-effective process.

References

[1] K.-J Kim, J.-S. Lim, T.-Y. Jung, C. Nam, and B.-C. Ahn, in *IDW.* (2002) p. 433.

[2] J. Kim, Y.-W. Lim, and S.-D. Lee, *Jpn. J. Appl. Phys.* **45**, 810 (2006).

[3] C. L. Yang, *Jpn. J. Appl. Phys.* **43**, 4273 (2004).

[4] J. H. Song and S. H. Lee, *Jpn. J. Appl. Phys.* **43**, L1130 (2004).

[5] T. B. Jung, J. C. Kim, and S. H. Lee, *Jpn. J. Appl. Phys.* **42**, L464 (2003).

[6] Y.-T. Kim, J.-H. Hong, H. Kim, and S.-D. Lee, in *SID'09 Dig.* (2009), p. 1662.

[7] Y. Xia and G. M. Whitesides, *Angew. Chem. Int. Ed.* **37**, 550 (1998).

[8] Y.-T. Kim, J.-H. Hong, T.-Y. Yoon, and S.-D. Lee, *Appl. Phys. Lett.* **88**, 263501 (2006).

[9] H. J. Ahn, S. J. Rho, K. C. Kim, J. B. Kim, B. H. Hwang, C. J. Park, and H. K. Baik, *Jpn. J. Appl. Phys.* **44**, 4092 (2006).

[10] J. S. Gwan *et. al., J. Appl. Phys.* **93**, 4936 (2003)

※ Parts of this work were presented in SID 2009.