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Trapping of defect point to improve response time via controlled azimuthal anchoring in a vertically aligned liquid crystal cell with polymer wall

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Abstract
Conventional multi-domain vertically aligned liquid crystal (LC) cells have defect points due to the collision of LC directors during the formation of multiple domains. In addition, the location of defects changes with time resulting in a slow response time. This paper proposes a robust vertically aligned LC cell, where the LCs are locked by polymer walls, and the azimuthal anchoring on the surface of the alignment layer is controlled by the polymerization of a UV curable reactive mesogen monomer. As a result, the defect points are trapped at a single position, resulting in a greatly improved response time.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Liquid crystal (LC) televisions are emerging rapidly because of their high-quality images through the adoption of wide-view LC modes, such as multi-domain vertical alignment (MVA) [1–3] fringe-field switching (FFS) [4,5] and in-plane switching (IPS) [6]. Among these, MVA modes do not require a rubbing procedure, which is an advantage in manufacturing. Indeed, there are several methods for forming multiple domains in a VA liquid crystal display (LCD). Among them, the MVA mode uses protrusions to form a multi-domain while a patterned VA (PVA) [7–10] employs patterned electrodes on the top and bottom substrates. However, both MVA and PVA modes are quite sensitive to external pressure in that the LC orientation is disturbed instantaneously with strong ripple marks upon the application of pressure. This phenomenon is particularly undesirable with touch panel LCDs. Another type of VA was suggested to suppress ripples, known as a locked-super homeotropic (LSH) cell, where the LC is surrounded by polymer walls [11–14]. In all VA modes, the vertically aligned LCs at the initial state are deformed in different directions in the presence of an electric field to generate the same phase difference according to the viewing angle in order to show wide viewing angle. Therefore, collisions between the LC directors near the domain boundary are unavoidable, which generates disclination lines with defect points [15–19] In addition, the location of these defect points moves until they are stabilized resulting in a slow rise time.

This paper proposes an improved LSH mode, named as quality-LSH (Q-LSH) mode, in which the polymer wall serves two purposes as the conventional LSH mode: it works as a spacer and it locks the chiral-doped LC in a confined area. In contrarst to the perfect vertical alignment without biased azimuthal anchoring in the typical LSH mode [11], surface pretilt angles are formed in an axially symmetric aligned configuration in each confined area through UV

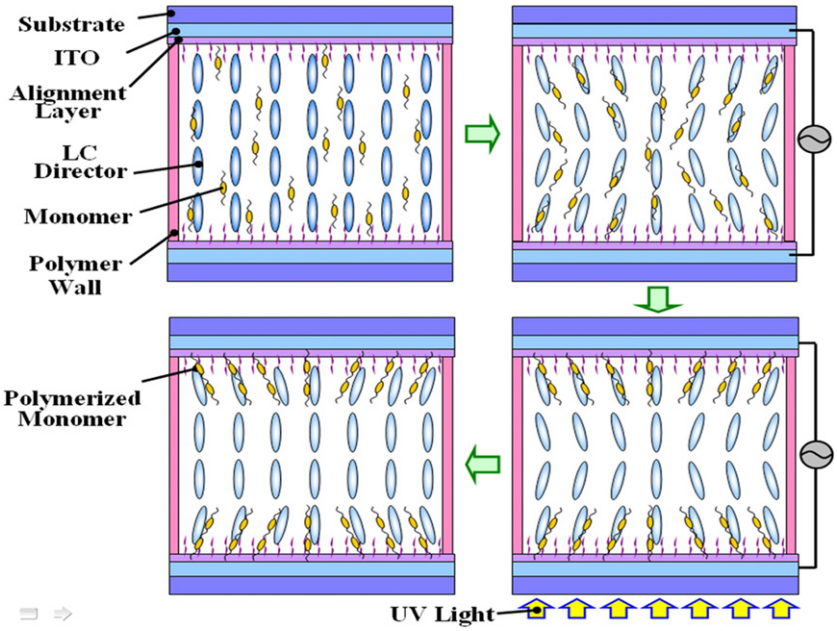

Figure 1. Schematic diagram of the processes for fabricating the Q-LSH cell with defined pretilt angles at the substrate surfaces.

polymerization of reactive mesogen monomer in the presence of an electric field in the Q-LSH cell. This means that azimuthal reorienting direction of the LC directors is defined when a voltage is applied, and thus molecular collision is minimized with trapped defect point, resulting in an improved response time. The cell fabrication conditions and detailed electro-optic characteristics of the Q-LSH mode are also discussed.

2. Experimental conditions and formation of surface pretilt angle

A chiral-doped super-fluorinated LC mixture ($\Delta\varepsilon = -4.9$, $\Delta n = 0.14$ at $\lambda = 589$ nm, chiral pitch $= 16\,\mu$m) from Merck was used. The LC material was mixed with RM-257 (from Merck), a reactive mesogen monomer, and Igracure 651 (from Ciba), a photo-initiator. The weight percentage of the monomer and photo-initiator relative to the LC was 0.1% and 0.001%, respectively. The mixture was heated to the isotropic temperature of the LC for 5 min. The LC was then cooled to room temperature and dropped on the bottom substrate of the cell using a one dropping method. An indium-tin-oxide (ITO) coated glass substrate with VA alignment layer on the surface has patterned polymer walls, which partition off each pixel, serving to both lock the LC directors and as column spacer. In this study, the spacer height was 4 μm, which is the same as the cell gap. After filling the LC, the bottom substrate was covered with another ITO-coated top substrate with the same VA alignment layer to form an LC cell.

Once the cell fabrication process was complete, the mixture was confined in a limited space, as shown in figure 1. Initially, the LC and RM-257 were aligned vertically due to the use of vertical alignment layers on both substrates. A voltage of 3.6 V_{rms} greater than the Freedericksz transition threshold (V_{th}) was then applied to the cell so that the reactive mesogen monomer and LC could be reoriented with a slight tilt angle from the surface in response to the electric field. In the presence of an electric field, the cell was exposed to UV light and thus the monomers were polymerized with a constant tilt angle at the surfaces through a photo-induced monomer diffusion process under optimal monomer weight per cent and UV curing conditions [10, 19–22]. Consequently, in the absence of an electric field, the LCs in the bulk relax to the original VA state while the surfaces have some defined pretilt angles. In this case, the azimuthal direction of the defined surface pretilt angle depends on the LC orientation at the surfaces generated by the bias voltage.

In the conventional LSH cell in which the LC orientation in the on state is defined only by the polymer walls surrounding the LCs, when $V > V_{th}$, collision of the LCs occurs as a result of the undefined azimuthal direction of the surface pretilt angle in the initial state, which instantaneously generates an undefined LC texture. Nevertheless, with time, it reaches a stable final state with a radial configuration of the mid-director due to chiral dopant with a defect point at the centre of each room [11, 14]. The orientation of the polymerized reactive mesogen at the surfaces follows the LC orientation because UV is irradiated at this stage when the orientation of the LCs has a defined pretilt angle with axially symmetric alignment in azimuth, as shown in figure 2.

3. Results and discussion

First, the voltage dependent transmittance curves of the conventional LSH and Q-LSH cells with a diameter of 80 μm were compared, as shown in figure 3. As indicated, the threshold voltage in the Q-LSH cell was reduced and the maximum transmittance was improved. This is because the azimuthal direction of the LCs at the surface with some pretilt angle is defined so that reorientation of entire LCs in the cell

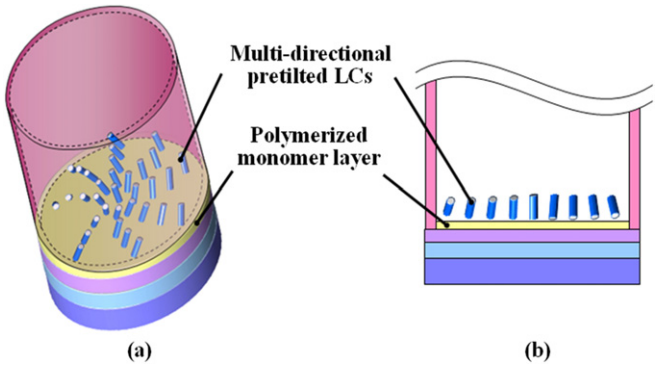

Figure 2. (*a*) Three dimensional and (*b*) cross-section of a unit cell of LSH showing the axially symmetric defined pretilt angle layer.

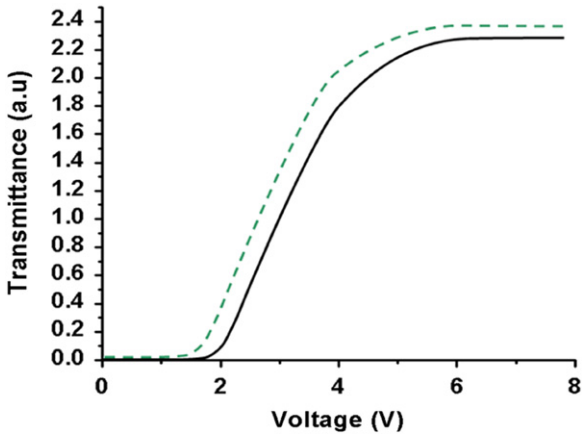

Figure 3. Measured voltage dependent transmittance of a conventional LSH cell (——) and a Q-LSH cell (----).

is guided in order to minimize the collision between each LCs while responding to the applied electric field in the Q-LSH cell. However, such a pretilt LC layer on the surface increases the amount of light leakage in the dark state resulting in a lower contrast ratio because the surface pretilt angle generates phase retardation under a crossed polarizer. However, the surface pretilt angle can be minimized in order to maintain a high contrast ratio if the RM curing voltage and concentration and UV exposure condition can be optimized [10].

A series of time-resolved textures and measured response times of the Q-LSH cell were compared with those of the conventional LSH cell in order to highlight the significance based on the existence and nonexistence of a defined pretilt angle. Figure 4 shows the results with the applied voltages that generate 90% of the maximum transmittance of the cells. In order to observe the size effect of the polymer walls, cells containing cylindrical polymer walls with diameters of 80 and 300 μm were evaluated. In the conventional LSH cells, the LC tilts down with a twist angle of 90^o from top to bottom with left handedness due to $d/p = 0.25$ when a voltage is applied; however, the azimuthal tilting-down direction of the LC is not defined. In this case, the LC is surrounded only by the polymer wall so that the LC texture is undefined at the time the voltage is applied and reaches the final stabilized texture with four brushes, as shown in figures 4(*a*) and (*c*). The LC cell with the 80 μm polymer walls takes approximately 25 ms

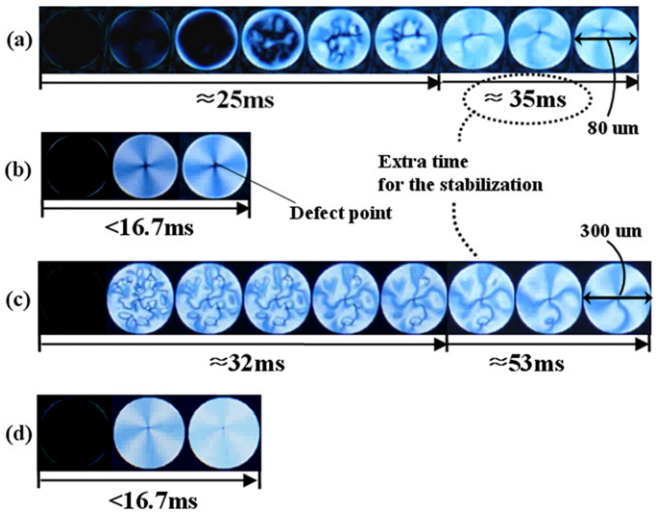

Figure 4. The time-resolved LC textures needed to reach 90% maximum transmittance according to the size of the polymer wall in the conventional LSH ((*a*) and (*c*)) and Q-LSH ((*b*) and (*d*)) cells.

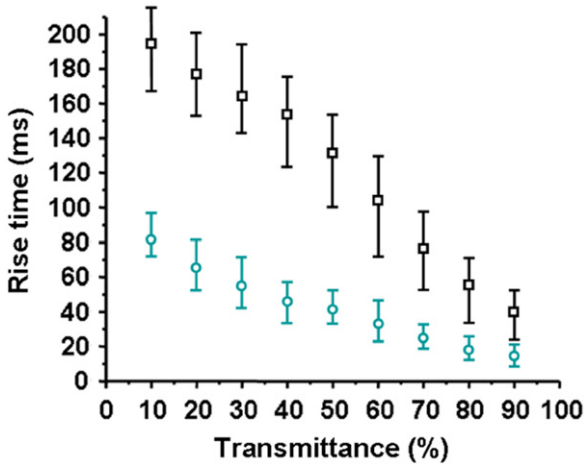

Figure 5. Measured rise times for the conventional LSH (square) and a Q-LSH (circle) cells.

for the four-brush texture to appear and another 35 ms to be stabilized. However, in the Q-LSH cell, the entire process takes less than 17 ms, as shown in figure 4(*b*). A similar behaviour was observed for the cell with a larger diameter polymer wall, indicating much faster stabilization of the LC texture in the Q-LSH cell than that in the conventional cell (see figure 4(*d*)). In addition, in the conventional cell, the location of a point defect with a defect strength of $S = +1$ is not fixed at the centre of the polymer wall with time. However, it is fixed at a single position in the Q-LSH cell. It is expected that the response time would be greatly improved in the Q-LSH cell because the defect point is fixed at one position. Figure 5 compares the rise time of the two cells at different grey levels. As expected, the response time of the Q-LSH cell was improved by more than 200% at all grey levels compared with the conventional LSH cell. Similar behaviour related to the defect points was observed even in the multi-domain twisted nematic cell [23, 24], reflecting the importance of controlling disclination lines in order to achieve a fast response time in multi-domain LC devices.

4. Summary

In summary, this paper reports a VA device where the LC directors are locked by polymer walls and the defect point is trapped at a single location within each hole through the formation of a surface pretilt on a defined azimuthal direction through the polymerization of a UV curable RM monomer. The device showed improved electro-optic characteristics, particularly regarding the response time. In addition, the device has intrinsic advantages exhibiting a wide viewing angle and strong endurance against external pressure [25], which are particularly desirable for multi-media displays.

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References

[1] Koma N, Baba Y and Matsuoka K 1995 *Soc. Inform. Display Tech. Digest* **26** 869
[2] Takeda A, Kataoka S, Sasaki T, Chida H, Tsuda H, Ohmuro K, Sasabayashi T, Koike Y and Okamoto K 1998 *Soc. Inform. Display Tech. Digest* **29** 1077
[3] Gu M, Ivan Smalyukh I and Oleg Lavrentovich D 2006 *Appl. Phys. Lett.* **88** 061110
[4] Lee S H, Lee S L and Kim H Y 1998 *Appl. Phys. Lett.* **73** 2881
[5] Yu I H, Song I S, Lee J Y and Lee S H 2006 *J. Phys. D: Appl. Phys.* **39** 2367–72
[6] Oh-e M and Kondo K 1995 *Appl. Phys. Lett.* **67** 3895
[7] Kim K H, Lee K, Park S B, Song J K, Kim S and Souk J H 1998 *Proc. 18th Int. Display Research Conf./Asia Display (Seoul, Korea, 28 September–1 October 1998)* pp 383–7
[8] Kim J H, Yeo Y S, Park W S, Lee S K, Ahn S H and Kim C W 2006 *Proc. 13th Int. Display Workshops (Otsu, Japan, 6–8 December 2006)* pp 858–61
[9] Lee G-D, Son J-H, Choi Y-H, Lyu J-J, Kim K H and Lee S H 2007 *Appl. Phys. Lett.* **90** 033509
[10] Kim S G, Kim S M, Kim Y S, Lee H K, Lee S H, Lee G-D, Lyu J-J and Kim K H 2007 *Appl. Phys. Lett.* **90** 261910
[11] Lee S H, Park S H, Lee M-H, Oh S T and Lee G-D 2005 *Appl. Phys. Lett.* **86** 031108
[12] Kim S G, Oh S T, Lee G D, Han J I, Lee C J and Lee S H 2006 *Proc. 26th Int. Display Research Conf. (Ohio, 18–21 September 2006)* pp 394–6
[13] Kim S M, Kim S G, Kim Y S, Lee H K, Lee M-H, Lee G-D, Lyu J J, Kim K H and Lee S H 2007 *Soc. Inform. Display Tech. Digest* **38** 742
[14] Kim S G, Kim Y S, Srivastava A K, Oh S T, Lee G-D and Lee S H 2008 *Curr. Appl. Phys.* **8** 142
[15] Yoshida H, Nakanishi Y, Sasabayashi T, Tasaka Y, Okamoto K, Inoue Y, Sukenori H and Fujikawa T 2000 *Soc. Inform. Display Tech. Digest* **31** 334
[16] Yoshiga M, Fukumoto M, Hamawaki Y, Unate T and Sunata T 2000 *Proc. 7th Int. Display Workshops (Kobe, Japan, 29 November–8 December 2000)* pp 211–4
[17] Jun S-I, Park W-Y, Kim I-G, Lee J-Y and Souk J-H 2002 *Soc. Inform. Display Tech. Digest* **33** 208
[18] Wu Y-H, Lee J-H, Lin Y-H, Ren H and Wu S-T 2005 *Opt. Express* **13** 7045
[19] Hanaoka K, Nakanishi Y, Inoue Y, Tanuma S, Koike Y and Okamoto K 2004 *Soc. Inform. Display Tech. Digest* **35** 1200
[20] Kang S W, Sprunt S and Chien L C 2002 *Macromolecules* **35** 9372
[21] Hasegawa R, Kidzu Y, Amemiya I, Uchikoga S and Wakemoto H 2007 *Soc. Inform. Display Tech. Digest* **38** 995
[22] Huang C-Y, Fung R-X and Lin Y-G 2007 *Japan. J. Appl. Phys.* **46** 5230
[23] Reichenstein M, Stark H, Stelzer J and Trebin H-R 2002 *Phys. Rev.* E **65** 011709
[24] Marenduzzo D, Orlandini E and Yeomans J M 2005 *Europhys. Lett.* **71** 604
[25] Kim S K and Lee S H, private communication