P-119: The Stabilized Bistable LC Mode for Flexible Display from Multi-rubbing on the PILC Structure

Ji-Hong Bae[1], Se-Jin Jang[1], Yoonseuk Choi[2], Chul Gyu Jhun[4], Jae Chang Kim[4], and Jae-Hoon Kim[1,2,3,*]
[1]Department of Information Display Engineering, Hanyang University,
[2]Research Institute of Information Display, Hanyang University,
[3]Deartment of Electronics and Computer Engineering, Hanyang University
17 Haengdang-Dong, Seongdong-Gu, Seoul, 133-791, Korea
[4]Department of Electronics Engineering, Pusan National University,
Jangjeon 2-dong, Geumjeong-gu, Pusan, 609-735, Korea

Abstract

We propose the stabilization technique for the memory state of bistable liquid crystal (LC) mode in the pixel-isolated LC (PILC) structure. To obtain the enhanced retention time of memory state, we apply the multi-rubbing method to create the partial 90° twisted domains in each sub-pixel as the seeds of stabilizing the π-twist states. The PILC structure provides the uniform and stable cell gap against various external deformations. The suggested structure can be very useful for portable flexible display applications with high quality device performance such as low power consumptions and good mechanical reliability.

1. Introduction

For the future ubiquitous circumstances, the portability of display device is highly important to diverse and numerous information without the restriction of time and place. The flexible display is one of the most promising devices for portable applications because it weighs light and can be easily rolled up to reduce its volume. Various researches for developing the flexible display have been widely performed so far [1-8]. Among these technologies, the liquid crystal (LC)-based flexible display is the most attractive technique because it has diverse merits such as full-color realization, well-established process, and good electro-optic characteristics [9]. Especially, the pixel-isolated LC (PILC) technique has successfully achieved the flexible liquid crystal display (LCD) with good device performances and high mechanical reliability with the wall-supporting structure [4,5]. However, for the portable applications, the advanced technique adopting new LC mode is necessary to deal with various mobile conditions like low power consumption.

In this paper, we demonstrated the stabilized bistable LC mode in the PILC structure. The dynamic and memory modes were simultaneously achieved in a single cell using the bistable chiral splay nematic (BCSN) scheme [10]. For displaying the motion-images, we can use the dynamic mode while the memory mode can be employed to paper-like applications such as E-books or E-papers. Also, the wall structure in each pixel provides the mechanical reliability of the device. Particularly, we developed the multi-rubbing method to increase the retention time in the memory mode. In order to obtain the stable memory state of the device, we have to create the seed of stabilization for π-twist state. By using the multi-rubbing technique, we made the 90° twisted domain in each sub-pixel as the seed. As the result, we obtained much enhanced retention time of π-twist state over 24 hours through whole sample area. This fabrication method for the stabilized bistable LC mode in the PILC structure can be helpful to construct the portable flexible display exhibiting the low power consumption and the reliable operation under various external deformations.

2. Device Configuration & Operation

The basic operational principle of our sample is the same as that of the conventional BCSN mode [10]. Three basic stable states in this mode are the splay, the bend (low bend and high bend), and the π-twist state. When we apply the vertical field to the sample, the low-bend and the high-bend states are obtained according to the amount of applied voltages. Therefore, the dynamic mode of the device can be obtained as we drive these two states by controlling an applied voltage. This driving scheme is very similar to that of the conventional OCB (Optically Compensated Bend) mode [11].

When we remove the applied vertical field at the high-bend state, the π-twist is obtained instead of the splay state because the high-bend and the π-twist states are in the same phase while the splay state is not. If we applied the horizontal field in this π-twist state, then we can get the splay state. Thus, we can realize the memory mode of device using these two stable states with the in-field driving. However, the π-twist state is easily transferred to the splay state spontaneously after short retention time unless we apply the appropriate stabilization techniques. One of the methods for stabilizing this memory mode is creating the 90° twisted LC structure around the π-twist state as the seed of stabilization [12].

In our study, we formed the 90° twisted LC domain in the sub-pixels by using the multi-rubbing method to obtain the stable retention time for the memory mode in the pixel-isolated structure as depicted in Figure 1. From this multi-rubbing process, we can realize the initial splay area and the seed area for memory mode stabilization simultaneously in the single pixel.

Figure 1(b) schematically illustrates the cross-sectional view of our stabilized bistable LC mode in the PILC structure. The rigid wall made by polymer maintains a stable and a uniform cell gap of device under various deformations. At the top substrate, the conventional homogeneous LC alignment layer was placed to induce the initial splay LC configuration while the multi-rubbed alignment layer was place in the bottom substrate. Remark that the 90° twisted domain is created around near side of the wall at the tail of arrow representing the second rubbing direction. We used the three terminal electrodes configuration for applying a vertical and a horizontal field simultaneously to realize the dual driving scheme. Note that the optimized condition for constructing the bistable LC mode is affected by various factors

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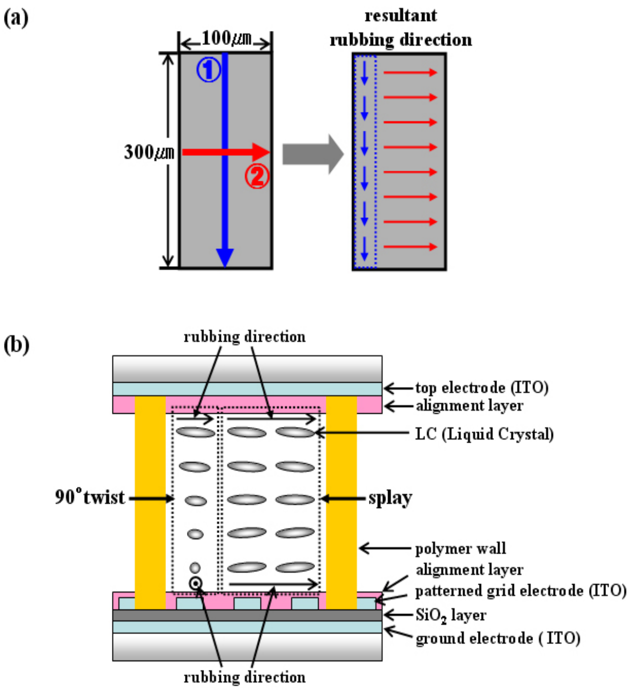


Figure 1. (a) The multi-rubbing method and the resultant rubbing direction in a single pixel. (b) Schematic illustration of the proposed stabilized bistable LC mode in the PILC structure.

such as the material characteristics, the cell gap, the helical twisting power, the boundary conditions of each pixel, and the field effect by an applied voltage.

3. Experimental

To confirm the stable operations and the electro-optic characteristics of our bistable LC mode, we demonstrated the proposed method on the glass substrate with PILC structure. The splay state of device was obtained by the parallel rubbing process of the LC alignment layer and the optimizations of material characteristics. A commercial polyimide, AL3046 from JSR (pre-tilt angle: 4~5°) and a nematic LC, MLC 6204 from E. Merck was used in this experiment. The birefringence (Δn) and dielectric anisotropy ($\Delta\varepsilon$) of used LC were 0.1481 and 35.2, respectively. The chiral dopant (S-811) was used to match the pitch of LC as 32.5µm which was adjusted to the ratio of cell thickness (d) and pitch (p) as 0.2 (d/p) for realizing the condition of bistability [13]. The size of each pixel was 300µm x 100µm, the width of single wall is 30µm, and the height of the wall (i.e. the cell gap of this device) is 6.5µm.

To apply the vertical and horizontal field freely, we used three terminal electrodes structure. For the fabrication of bottom glass substrate, SiO_2 film is coated as the insulation layer with the thickness of the 2320Å on the transparent ground electrode of indium tin oxide (ITO). Then we deposited and patterned grid electrode (ITO) on the insulation layer by photolithography. The width and the gap of patterned grid electrode are 4µm and 6µm, respectively. After that, we generated the pixel-isolated wall structure using the negative photoresist SU-8 (Micro-Chem) by a photolithographic patterning method. SU-8 is highly applicable for the rigid polymer wall because it shows the superior physical, chemical stabilities after the heat treatment and it doesn't react with LCs. As the top substrate, simple ITO glass substrate was used.

4. Results and Discussion

In Figure 2, the spontaneous transition of π-twist to splay was shown in the sample without applying multi-rubbing process. We rubbed the polyimide in the parallel direction of wall structure. We can get π-twist state after removing applied voltage in high-bend state. However, the π-twist state is relaxing spontaneously to splay state within few minutes as shown in Figure 2. The direction of phase transition (π-twist to splay) is parallel to the rubbing direction as depicted in the figure. If we changed the rubbing direction perpendicularly, the result was the same. This means that the π-twist state can be easily unwound and transferred to the splay state if there is no seed of stabilization. Note that these transition phenomena occurred randomly and differently (the speed and the amount) through the whole sample area.

Figure 3 shows the microscopic textures under crossed polarizers of the sample which was fabricated with the multi-rubbing process. The white (W) state of the pixel was observed near the polymer wall while the dark (D) state was monitored at the other side. The 90° twisted LC structure exhibits the white state and the splay state shows the dark state under such optical settings. This white part turned into the dark state as we rotated the analyzer by 90° from the beam guiding effect of the TN mode in LCDs [14]. Thus, we can conclude that the 90° twisted domain and the splay domain is successfully achieved uniformly in the single pixel by using our multi-rubbing method.

We also optimized rubbing condition for fabricating the high quality device. Figure 4 shows the textural change of the LC samples with polarizing microscope which have different rubbing conditions. As we increased the strength of the 2nd rubbing process while we fixed the strength of the 1st rubbing, more stable uniform textures were observed in the sample. It believed that the aligning effect of 2nd rubbing is gradually increased as enhancing the strength and eventually dominates the entire pixel area.

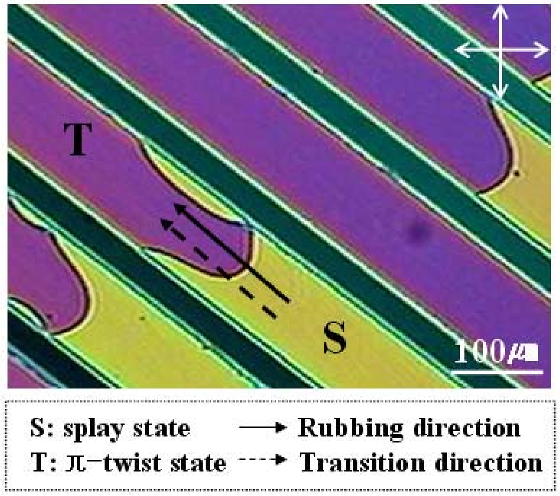


Figure 2. Observation of the problem of the unstable memory state (The π-twist state is transferred to the splay state after short retention time).

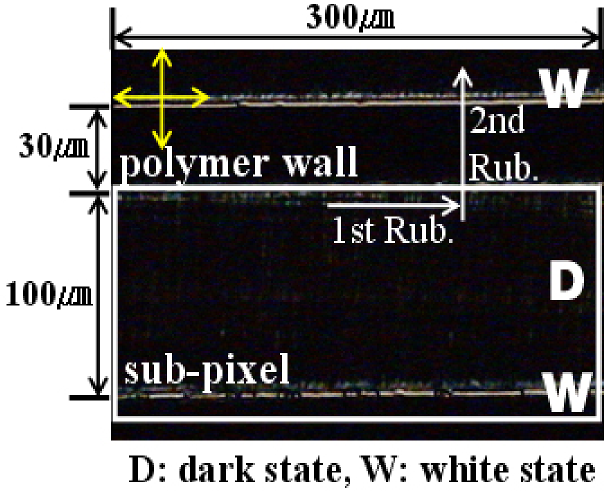
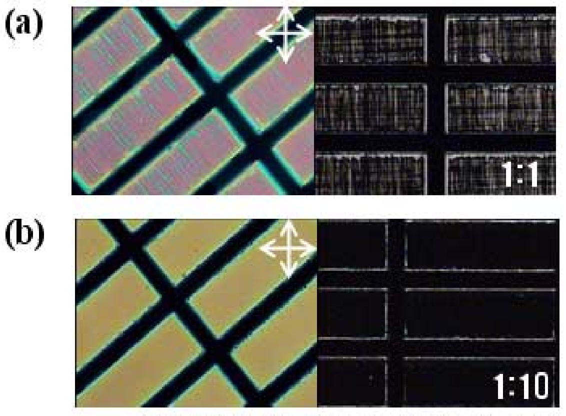


Figure 3. Microscopic texture of the single pixel fabricated by the multi-rubbing process.

However, if we performed the 2nd rubbing too strongly, the multi-alignment of LCs was not observed. We could obtain the most fine sample in the case of 1:10 (first rubbing strength : second rubbing strength) sample in this study.

Figure 5 shows that the memory property and driving performance of sample with multi-rubbing process. When no external voltage was applied, the initial splay state was obtained (Figure 5(a)). As we increase the vertical field, the LC directors are re-orientated to the vertical direction and the bend state was obtained. In this circumstance, the transmittance is gradually reduced and saturated. When we removed the external field, the high-bend state becomes the π-twist state as shown in Figure 5(b). This twist state was maintained after 24 hours which means the retention time of our memory mode can be dramatically increased by using the proposed technique. The 10V was enough to obtain the high-bend state from the voltage-transmittance characteristic depicted in the Figure 5(c). Note that the extinction ratio between two memory states is rather small and should be improved in the further study by optimizing the parameters.



* X:Y = first rubbing : second rubbing

Figure 4. The microscopic textures of the multi-rubbing samples with different rubbing conditions.

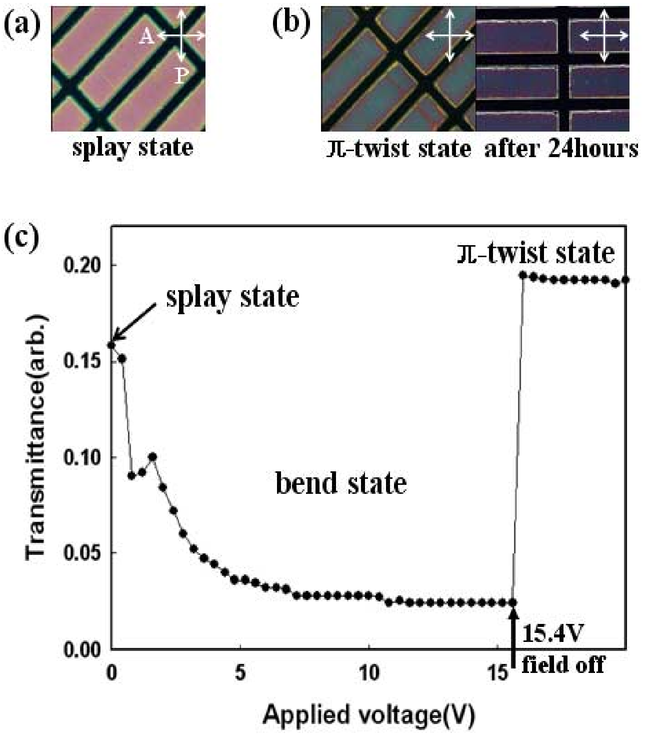


Figure 5. Dynamic characteristics of proposed bistable LC mode: (a) Microscopic images of initial splay state in the PILC structure. (b) Microscopic images of the π-twist state. The left photograph is the texture after just removing the applied vertical field and the right is the texture observed after 24 hours. (c) Voltage-transmittance curve with the vertical field applications.

5. Conclusion

In summary, we proposed the fabrication method of stabilized bistable LC mode in the PILC structure. The simultaneous realization of the dynamic and the memory mode supports the low power consumption for portable applications. Also, the polymer wall of the PILC structure provides the reliable operation of the device against the external shocks and deformations. The retention time of memory state was noticeably extended (over 24 hours) by creating the seed area (90° twisted LC domain) in the pixel by multi-rubbing technique. This fabrication technique of stabilized bistable LC mode is highly applicable to the future portable roll-up display with low power consumption and good mechanical reliability.

6. Acknowledgements

This research was supported by one of the 21st century Frontier R&D programs funded by the Ministry of Commerce, Industry and Energy of the Korean government.

7. References

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