P-14: Novel Stability Enhancing Technique for Flexible LC Display by using Rigid Spacer Array and Micro-Contact Printing

Se-Jin Jang[1], Ji-Hong Bae[1], Min-Soo Shin[1], Yoonseuk Choi[2], Hak-Rin Kim[2], Sang Il Kim[3], JunHyung Souk[3], and Jae-Hoon Kim[1,2*]

[1]Department of Information Display Engineering, Hanyang University, 17 Haengdang-Dong, Seongdong-Gu, Seoul, 133-791, Korea

[2]Reserach Institute of Information Display, Hanyang University, 17 Haengdang-Dong, Seongdong-Gu, Seoul, 133-791, Korea

[3]Samsung Electronics, LCD R&D Center, San 24 Nongseo-Dong, Giheung-Gu, Yongin-City, Gyeonggi-Do, 449-711, Korea

Abstract: *In this work, the novel combined technology for maintaining constant gap between two flexible substrates was investigated. The self-gathering adhesive polymer structure to stick flexible substrates was generated by using the rigid columnar spacer array and a micro-contact printing (μCP) method. The proposed flexible liquid crystal display (LCD) structure showed fine optical properties as well as enhanced mechanical stability for flexible display application under assorted deformations. Moreover, this technique can easily inherit most advantages of traditional LCD technology such as low driving scheme, established process and LC mode selection freedom within a simple fabrication procedure. Therefore, this method can be a powerful candidate for realizing practical flexible display with enhanced mechanical stability and high performance.*

Keywords: flexible liquid crystal display; mechanical stability; micro-structure; micro-contact printing; rigid spacer.

Introduction

In the developing display technology, the reliable flexible devices to be stable for various deformations and more easy portability are highlighted due to its multi-functional application [1]. In the term described, the flexible display adopts the soft substrates such as plastic. Especially, the LC-based flexible display is viably studied because it is the most dominant and advanced technique in that area [2-6].

In flexible displays, the maintenance of constant gap between two flexible substrates under various external conditions is a key issue to provide stable and uniform operation of the system. Especially, this is highly essential to the LC-based flexible display which is most dominant and advanced technique in the area. Nevertheless, although recent effortful developments like pixel isolated liquid crystal (PILC) structure [5,6] have shown the enhanced performances, it has still remained to solve the problems such as complex fabrication, induced defects from polymer wall or residual polymer and especially narrow display application range from limited LC mode. Especially, the distortion tolerance by bending, cracking of tension, delaminate buckling of compression should be solved to get a high quality flexible liquid crystal display (LCD).

In this work, we focused on the self-gathering adhesive polymer layer by using the rigid columnar spacer array and a micro-contact printing (μCP) [7] method. The designed pillar spacer array with μCP bonding method provides the maintenance of constant gap between two flexible substrates as well as good adhesion properties.

This technique of columnar spacer array and μCP method is more effective for the application of assorted flexible display structure with a simple process [8]. Moreover, the prominent electro-optic characteristics of flexible LCD is guaranteed because the capillary filling effect of designed multi-column spacer array generates a self-gathering structure of adhesive material without overflow.

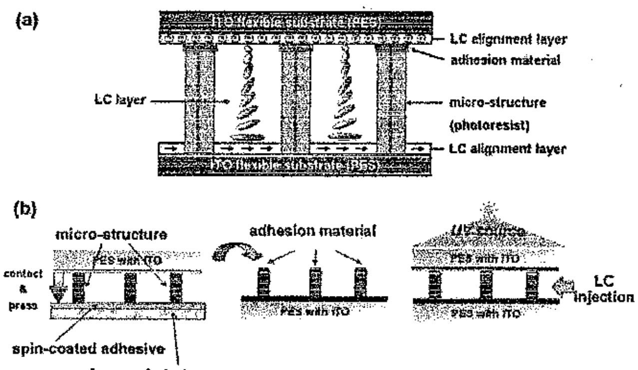

Figure 1. (a) Device configuration of flexible LCD mode based on a micro-structure (b) Fabrication procedure of the device using μCP method

Device Configuration

A schematic diagram of suggested structure is shown in Fig. 1(a). Two flexible substrates are tightly assembled each other by the adhesive material placed on the top of micro-column structure. The pillar array maintains stable and uniform gap of device through whole area by a similar mechanism of the micro-wall structure in previous PILC configuration [5,6]. However in our configuration, unlikely to the PILC case, self-gathering adhesive concept of assembling technique provides LC alignment on the top substrate can be controllable. This assures that we can obtain the freedom for

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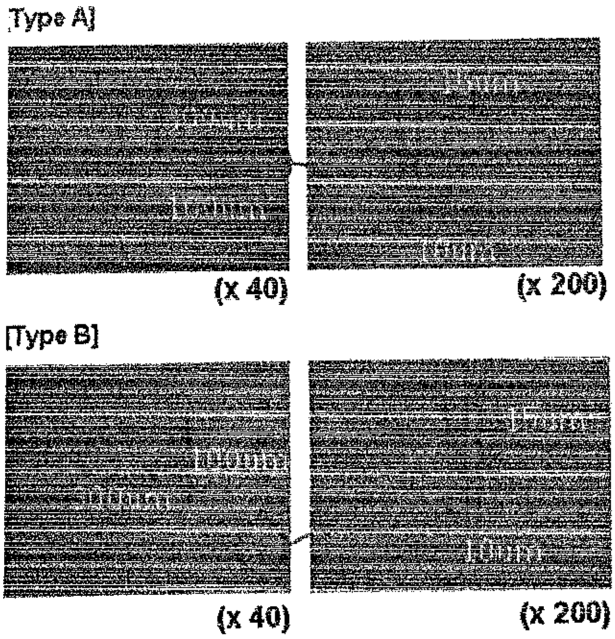
igning LC mode and easily adopt this method for diverse cible display applications. In this paper, most popular sted LC structure was demonstrated as an example of erse application (see Fig. 1 (a)).

assemble two substrates, μCP method is employed as istrated in Fig. 1(b). The UV curable optical adhesive lymer SK-9 (Optical Bond) was placed on the top of cro-columnar structure by contacting and pressing as own in the figure. Then the two substrates are assembled a simple UV irradiation. Note that multiple adhesion ints of rigid spacer array guarantee mechanical stability of vice at the edge of each pixel. SU-8 (Microchem) was used a photoresist material.



igure 2. The photographs of designed micro-structure of columnar spacer array. Circled insets in left figures are magnified at the right by 5 times (x40 to x200). Type A array is based on the two pillar structure while Type B does on the four column.

ligid Columnar Spacer Design

'he configuration of designed rigid columnar spacer is lustrated in the Fig.2. We divide the conventional single illar structure into the sub-parts to prevent overflow of dhesion materials and confine excessive agent in spacer area. By the capillary force between pillars, liquid adhesive slides nto the multi-column spacer at the moment of contact and be olidified by UV irradiation providing strong adhesion of two ubstrates and confined structure of adhesion material. Two ypes of design were demonstrated to check the mechanical tability and overflow effect variation. Type A rigid spacer ave two pillar structures of 15μm × 40μm with 100μm, 300μm of lateral spacing, while type B have four columnar structures of 15μm diameter with the same spacing as shown n the figure.

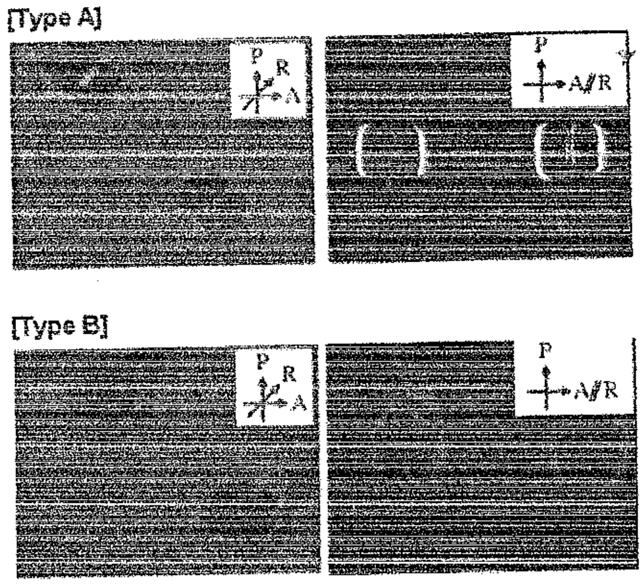


Figure 3. The microscopic images of LC textures under crossed polarizers around the rigid pillar spacer. Rubbing direction is parallel to the analyzer at the right dark images while that is 45 degree twisted to the analyzer at the left.

Results and Discussion

To examine the mechanical stability and the cell gap reliability of suggested configuration, we fabricated the basic planar alignment of LC sample on the popular plastic substrate of PES (polyethersulphone). PES shows a good stability for heat, chemical contamination and mechanical distortion.

In first, we checked the LC textures after fabricating a test sample. The clear gathered structure of adhesive polymer was observed in the microscopic images of LC sample as shown in Fig. 3. From the widely uniform texture images, we can confirm that the multiple adhesion contact points between two substrates by μCP guarantee a mechanical stability of flexible display as well as a simple process. From the capillary effects, the self-gathering phenomenon was more completed in Type B (see Fig. 3), which we can expect that this structure can be more stable and effective to show better adhesion properties and maintain the cell gap against the external forces. Note that the small boundary effect disturbs the LC alignment around the columnar spacer in the figure.

After μCP assembling process, the cross section was observed by SEM (scanning electron microscope) to confirm the confined adhesive polymer structure as depicted in Fig. 4 (a). Adhesive material was placed on top of micro-pillar structure, and confined structure of adhesive polymer was monitored within the pixel boundary.

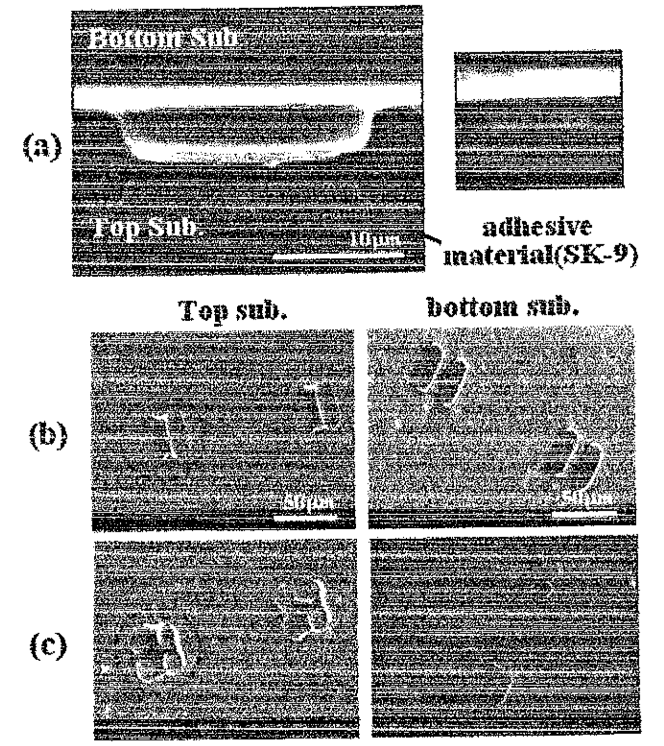


Figure 4. (a) SEM image of cross section after using μCP method. (b) and (c) is top and bottom substrate after detaching sample, respectively.

Fig. 4 (b) and Fig. 4 (c) show the SEM images of the top and bottom substrates after opening the sample and removing the LCs in inter- and intra pixel regions. The area where the adhesive material was placed to the micro-pillar structure on was obviously observed in the dotted regions of Fig. 4 (b) and Fig. 4 (c). This is consistent with the results of monitoring LC textures in the Fig. 3. As the result, we confirmed the designed rigid spacer can create the self-gathering isolated adhesive polymer structure from the capillary effect.

In next, the sample is fixed in the air with increasing the additional loads to check the adhesion reliability. Table 1 shows the measured maximum capable load without breaking sample in four measurements. In experimental results, our sample stands up the average load of 2.54 and 4.56 N/cm^2, for type A and type B, respectively. This result can be easily understood by matching the LC texture observations and our general expectation from the pillar design.

Table 1. Adhesion breaking test by increasing weight of the loads. Two types of rigid spacer array was tested by μCP bonding process.

(Dimension: N/cm^2)

Experiment	1	2	3	4
Type A	1.89	3.38	1.89	2.36
Type B	4.35	5.00	5.00	3.01

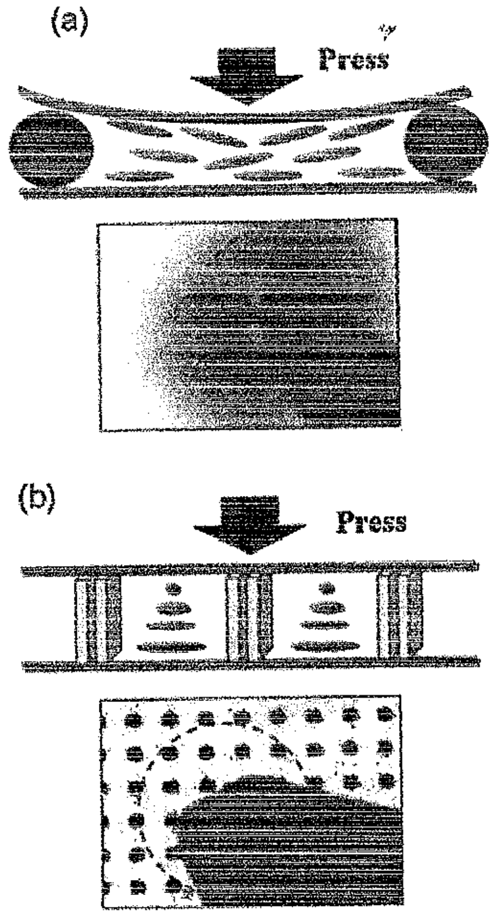


Figure 5. The schematic illustration of LC configuration under external pressure and texture of the sample (a) conventional ball spacer case (b) our rigid micro-structure case

As described earlier, one of the main advantages of our suggested technique is to be adjustable for diverse LC mode which is essential to establish high quality and various flexible displays while the other LC based flexible techniques have restricted LC mode suitability. So, in next experiment, homogeneous LC aligning agent Nylon 6 was used and rubbed in the crossed direction to obtain twisted LC geometry sample. TN is the most general configuration for practical display application as well known. Surely, depending on the LC aligning agent and rubbing direction, we can easily realize different LC mode with our method. A commercial nematic LC (MJ00993 from E. Merck) was utilized in this experiment and its birefringence (Δn) and dielectric constant ($\Delta \varepsilon$) is 0.151 and 11.1, respectively. The crystal temperature of used NLC was 101°C and the cell gap was maintained as 3μm by rigid photoresist micro-structure.

In the mechanical stability test, the micro-structure sample was compared to the conventional ball spacer type. Typical structure is weak to an external pressure due to the lack of substrate supporting system in the pixel area [Fig. 5 (a)], otherwise, our micro-column rigid spacer sustains stable cell gap through the whole sample as shown in the press test due to the micro-structure and strong bonding [Fig. 5 (b)].

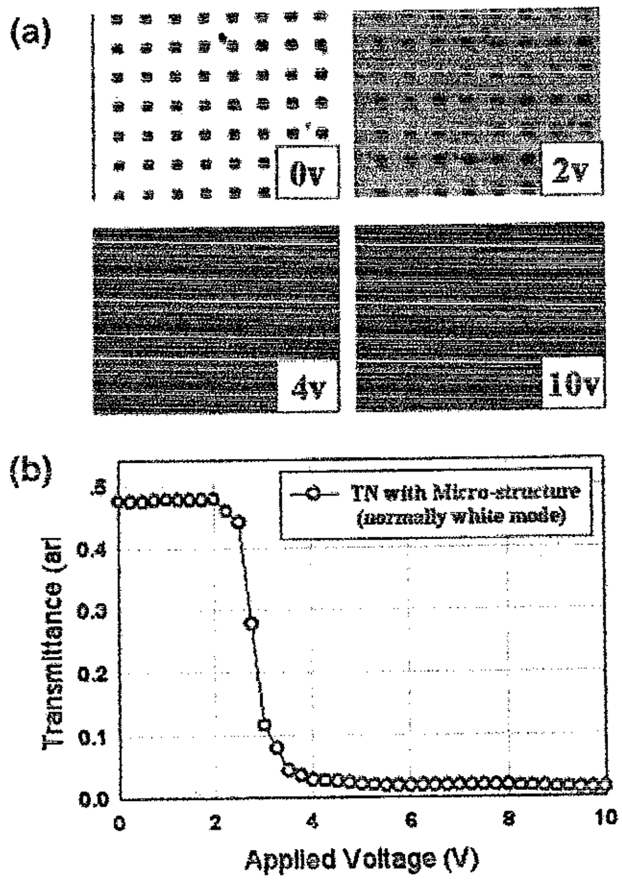


Figure 6. (a) Photograph of LC texture change under various applied voltages. Each image are taken under 0V, 2V, 4V and 10V, respectively (from top left, right, bottom left, right). (b) V-T curve of our TN sample with plastic substrate at normally white mode.

Subsequently, we checked out the electro-optic (EO) characteristics of TN structure to assure stable operation of the device in final. In Fig. 6 (a), LC texture change is monitored with various applied voltages. In the normally white configuration, TN sample is placed under crossed-polarizers with one of rubbing direction is parallel to the polarizer. As depicted in the figure, LC textures was get dark as increasing applied voltage and complete dark image was observed at the applied voltage of 10 V. Voltage-transmittance curve of the sample was measured in Fig. 6 (b). From the experimental data, we found that the performance of our flexible TN configuration based on a micro-structure was comparable to that of the conventional one.

As the result, we can conclude that the mechanically stabilized flexible LCD can be acquired by using our assembling technique with a simple fabrication and a LC mode selection freedom. The suggested method can be highly useful to realize the flexible LCD with reliable device performance. Note that optimization for various device parameters and detailed studies for mechanical stability remain to be explored.

Conclusion

We have demonstrated the stability-enhanced novel flexible LCD by using the micro-column spacer array and the μCP assembling technique. Designed pillar spacer array creates that the confined structure of adhesive polymer by capillary effect and μCP bonding supports the good adhesion of two flexible substrates. In addition, suggested techniques can easily adopt diverse LC mode because the control of LC alignment at top substrate is possible, diverse flexible LCD can be realized. As an example, we have demonstrated a flexible TN LC mode sample with the press test and EO measurements. From the experimental results, we can confirm that the much stabilized structure was achieved by a simple fabrication procedure showing the same display performances to the conventional one. In conclusion, this cell gap spacing and substrate assembling techniques based on the rigid spacer and μCP bonding method are expected to be highly useful for manufacturing flexible display with versatile usage.

Acknowledgement

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References

1. Edited by G. P. Crawford, "Flexible Flat Panel Display," *John Wiley & Sons*, 2005.
2. Comiskey B., J. D. Albert, H. Yoshizawa, and J. Jacobson, "An electrophoretic ink for all-printed reflective electronic displays," *Nature*, Vol. 394, no. 6690, pp. 253-255, 1998.
3. Burroughes J. H., D. C. Bradley, A. R. Brown, R. N. Marks, K. Mackay, R. H. Friend, P. L. Burns, and A. B. Holmes, "Light-emitting diodes based on conjugated polymers," *Nature*, Vol. 347, no. 6293, pp. 539-541, 1990.
4. D. Braun, and A. J. Heeger, "Visible light emission from semiconducting polymer diodes," *Appl. Phys. Lett.*, Vol. 58, issue 18, pp. 1982-1984, 1991.
5. Jung J.-W., S.-K. Park, S.-B. Kwon, and J.-H. Kim, "Pixel-Isolated Liquid Crystal Mode for Flexible Display Applications," *Jpn. J. Appl. Phys.*, Vol. 43, no. 7A, pp. 4269-4272, 2004.
6. Jang S.-J., J.-W. Jung, H.-R. Kim, M.Y. Jin, and J.-H.Kim, "Stability-Enhanced Pixel Isolation Method for Flexible Liquid Crystal Displays," *Jpn. J. Appl. Phys.*, Vol. 44, no. 9A, pp. 6670-6673, 2005.
7. Xia Y., and G. M. Whitesides, "Soft Lithography," *Angew. Chem. Int. Ed.*, Vol. 37, issue 5, pp. 550-575, 1998.
8. Jang S.-J., J.-H. Bae, Y. Choi, H.-R. Kim, S. I. Kim, J.H. Souk, and J.-H. Kim, "Stability Enhanced Flexible Liquid Crystal Display based on a Micro-Structure," *Mol. Cryst. Liq. Cryst.*, submitted, 2006.

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