Stability-enhanced Flexible Liquid Crystal Display using microstructure and micro-contact printing assembling technique

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

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

[3]Samsung Electronics, LCD R&D Center, Yongin-City, Gyeonggi-Do, Korea

*jhoon@hanyang.ac.kr

In this work, the combined technology to maintain constant gap between two flexible substrates was investigated. The self-gathering adhesive polymer structure was generated by using the rigid columnar spacer array and a micro-contact printing (μCP) method. The proposed structure showed the fine optical properties as well as enhanced mechanical stability for flexible display application under the variegated deformation. These techniques can inherit most advantages of conventional liquid crystal displays (LCDs) technology such as low driving scheme, established process and LC mode selection freedom within a simple fabrication procedure. The self-gathering adhesive polymer structure is expected to be useful for realizing practical flexible display with enhanced mechanical stability and high performance.

1. Introduction

In these days, the display industry requires reliable flexible devices for the variegated deformation and more easy portability [1]. In the terms desired, 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]. Nevertheless, currently studied liquid crystal display (LCD) technology has various advantages such as wide view angle, high contrast, fine optical properties and very thin structure. It has to be considered to keep developing enhanced technique like the reduction of productivity through simple fabrication process.

For solution, pixel isolated liquid crystal (PILC) structure [5,6] has been proposed and verified to show an enhanced performances, it has still remained to solve the problems such as complex fabrication and narrow application range. Especially, we cannot help fixing various problems such as the distortion tolerance by bending, cracking of tension, delaminate buckling of compression and reducing defects from polymer wall or residual polymer to get a high quality flexible 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 the columnar spacer array and μCP method is more effective for the application of assorted flexible display structure with a simple process. Moreover, this method can provide the prominent electro-optic characteristics of flexible LCD because the capillary filling effect of designed multi-column spacer array generates a self-gathering structure of adhesive material without overflow.

2. 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 the

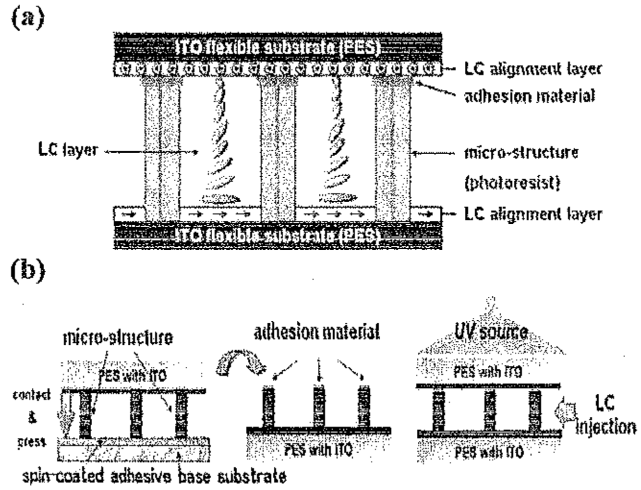


Fig. 1. (a) Device configuration of flexible LCD mode based on a microstructure (b) Fabrication procedure of the device using μCP method

similar mechanism of the micro-wall structure in previous PILC configuration. 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 designing LC mode and easily adopt this method for diverse flexible display applications.

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

2. Rigid Columnar Spacer Design

The configuration of designed rigid columnar spacc is illustrated in the Fig.2. We divide the conventional single pillar structure into the sub-parts to prevent overflow of adhesion materials and confine excessive agent in spacer area. By the capillary force between pillars, liquid adhesive slides into the multi-column spacer at the moment of contact and be solidified by UV irradiation providing strong adhesion of two substrates and confined structure of adhesion material. Designed

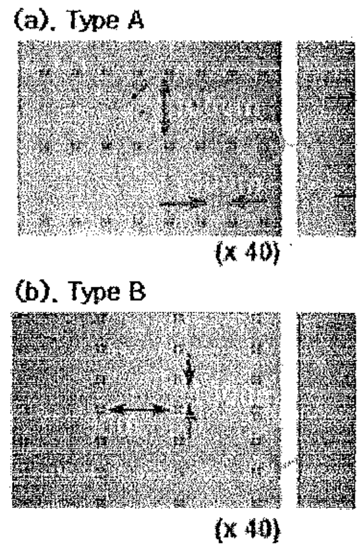


Fig. 2. The photographs of structure of columnar spacer based on the two pillar spacer four columnar construct

rigid spacer structure has four of 15μm diameter with 10μm sp area and the array was made lateral spacing (x-y direction) a 2 (a) and (b).

3. Results and Dis

To examine the mechanical s gap reliability of suggested demonstrated the basic ECB (el birefringence) LC sample on

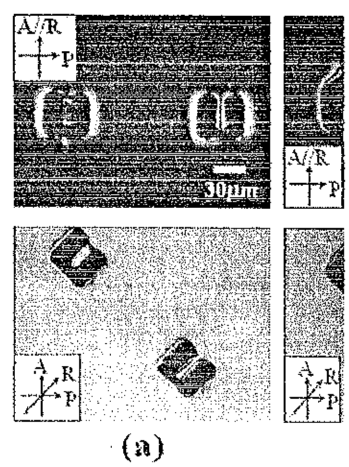


Fig. 3. The photographs of I crossed polarizers around the Rubbing direction is parallel the right dark images while twisted to the analyzer at the l

plastic substrate (PES). Multiple adhesion contact points between two substrates by μCP guarantee a mechanical stability of flexible display as well as a simple process compared to the polymer wall structure. The clear gathered structure of adhesive polymer was observed in the texture of LC sample as shown in Fig. 3. From the capillary effects, the self-gathering phenomenon was more completed in Type B, 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.

In next, the sample is fixed in the air with increasing the additional loads to check the adhesion reliability. Table 1 shows that the measured maximum capable load without breaking sample by four times. In experimental results, our samples stand up the load about 2.54 and 4.56 N/cm^2, for type A and type B, respectively. Note that the small boundary effect disturbs the LC alignment around the columnar spacer in the figure. This result can be easily understood by matching the LC texture observations and our general expectation from the pillar design.

As described earlier, one of the main advantages of our 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 demonstration, homogeneous LC aligning agent Nylon 6 was used and rubbed in the crossed direction to obtain twisted LC alignment of sample. Surely as depending on the LC aligning agent and rubbing direction, we can easily realize different LC mode by using suggested method. A commercial nematic LC (MJ00993 from E. Merck) was utilized in this experiment and its birefringence (Δn) and $\Delta\varepsilon$ is 0.151 and 11.1, respectively. The crystal temperature of NLC was 101°C and the cell gap was maintained as 3μm by rigid photoresist micro-structure.

(**Dimension: N / cm^2**)

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

Table 1. Adhesion breaking test by increasing weight of the loads. Sample structure employed the two types of pillar structure as shown in Fig. 3(a) and Fig. 3(b) by μCP method.

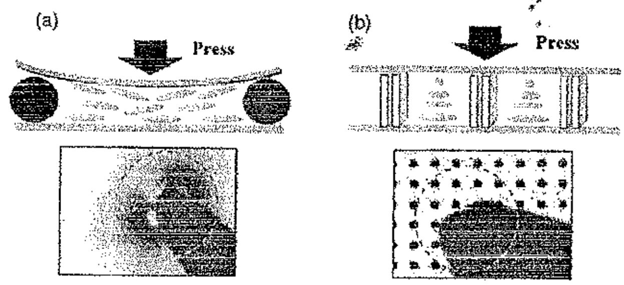


Fig. 4. The schematic illustration of LC configuration under external pressure and texture of the sample (a) conventional ball spacer case (b) our rigid micro-structure case

In the mechanical stability test, the micro-structure sample is 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. 4(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. 4(b)].

Subsequently, we check out the electro-optic (EO) characteristics of TN sample to assure stable operation of the device. In the normally white configuration, TN sample is placed under crossed-polarizers with one of rubbing direction is parallel to the polarizer. In the experimental observations, LC textures was get dark as increasing applied voltage and complete dark image was observed at the applied voltage of 10V. The voltage-transmittance curve of the sample was represented in Fig. 5. From the experimental data, we found that the performance of our flexible TN sample based on a micro-structure was comparable to that of the conventional one.

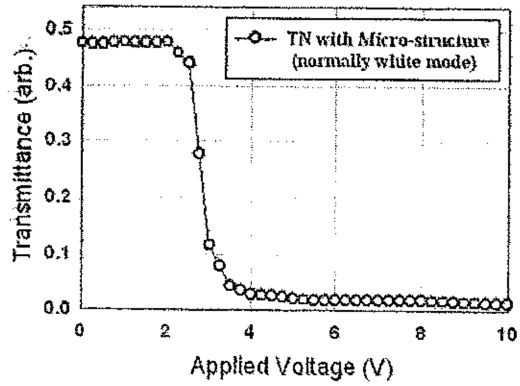


Fig. 5. V-T curve of our TN sample with plastic substrate at normally white mode.

As the result, we 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.

4. 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. As an example, we examined a flexible TN LC mode with the press test and EO measurement. From the experimental results, we confirmed that much stabilized structure was achieved by a simple fabrication procedure. 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. In conclusion, this assembling technique based on the flexible LC mode is expected to achieve a critical role in the practical application for manufacturing flexible display with versatile usage.

Acknowledgement

This research was supported by Samsung Elctronics LCD R&D Center and a grant (F0004052) from Information Display R&D Center, one of the 21st century Frontier R&D programs funded by the Ministry of Commerce, Industry and Energy of the Korean government.

References

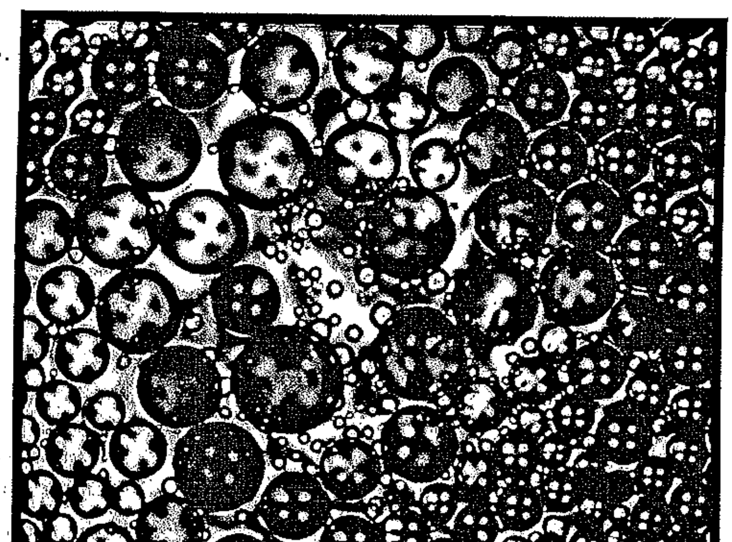
[1] Edited by G. P. Crawford, "Flexible Flat Panel Display", John Wiley & Sons, Chichester, (2005).
[2] B. Comiskey, J. D. Albert, H. Yoshizawa and J. Jacobson, Nature, **394**, 253 (1998).
[3] J. H. Burroughes, D. C. Bradley, A. R. Brown, R. N. Marks, K. Mackay, R. H. Friend, P. L. Burns and A. B. Holmes, Nature, 347, 539 (1990).
[4] D. Braun and A. J. Heeger, Appl. Phys. Lett., **58**, 1982 (1991).
[5] J.-W. Jung, S.-K. Park, S.-B. Kwon and J.-H. Kim, Jpn. J. Appl. Phys., **43**, 4269 (2004).
[6] S.-J. Jang, J.-W. Jung, H.-R. Kim, M.Y. Jin and J.-H.Kim, Jpn. J. Appl. Phys., **43**, 6670 (2005).
[7] Y. Xia and G. M. Whitesides, Angew. Chem. Int. Ed., **37**, 550 (1998).

Proceedings of the 9th

KOREA LIQUID CRYSTAL CONFERENCE

Chungnam National University, Daejeon, Korea

July 21 - 22, 2004



Organized by
Korea Liquid Crystal Society
Institute of Quantum Systems

CONTENTS

INVITED and ORAL