Novel spacing technology for versatile flexible display applications

Se-Jin Jang[1,]*, Ji-Hong Bae[1], Min-Soo Shin[1], Yoonseuk Choi[2], Hak-Rin Kim[2], Sang Il Kim[4] JunHyung Souk[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]Department of Electronics and Computer Engineering , Hanyang University,
17 Haengdang-Dong, Seongdong-Gu, Seoul, 133-791, Korea
[4]Samsung Electronics, LCD R&D Center, San 24 Nongseo-Dong, Giheung-Gu, Yongin-City, Gyeonggi-Do, Korea
Phone: +82-2-2220-0343, E-mail: sepal1004@ihanyang.ac.kr

Abstract

We have demonstrated the novel technique for spacing two flexible substrates in stable by using rigid pillar spacer array and micro-contact printing assembling technique. Specially designed columnar structure generates self-collected adhesive polymer feature results in a good adhesion and a high mechanical stability to the external bending deformations.

1. Introduction

The technologies of flat panel display (FPD) are most growing and evolving industry for last few decades. Especially, the flexible display technologies are extensively developed in recent years since it offers excellent portability, such as very thin packaging, lightweight and flexibility [1]. For the realization of flexible display, diverse approaches are performed so far by adopting electrophoresis, organic light emitting diodes (OLED) and liquid crystal display (LCD) technologies [2,3]. Among these, LCD is a good candidate for flexible display because of its advantages such as material stability, high infra and various dynamic/memory/reflective modes capability. However, there are still critical problems to fabricate commercially available plastic LCDs with current technologies based on the conventional substrates. One of these is the maintenance of constant gap between two plastic substrates to provide the 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 have shown the enhanced mechanical stabilities to an external forces, it has remains to be solved the limits such as complex fabrication, induced defects from polymer wall or residual polymer and especially narrow display application range [2,4].

In this paper, we demonstrate the novel technology for obtaining the stable spacing of flexible display using a new concept design of columnar rigid spacer and the micro-contact printing (μCP) method [5]. The pre-designed pillar spacer array with μCP bonding provides the precise and stable cell gap of flexible display as well as good adhesion properties and high mechanical reliability. Moreover, the capillary filling effect of designed pillar spacer offers a self-isolated structure of adhesive material without overflow.

2. Design of pillar structures

Figure 1 (a) showns fabrication procedure of the device using μCP method. Adhesive material of UV

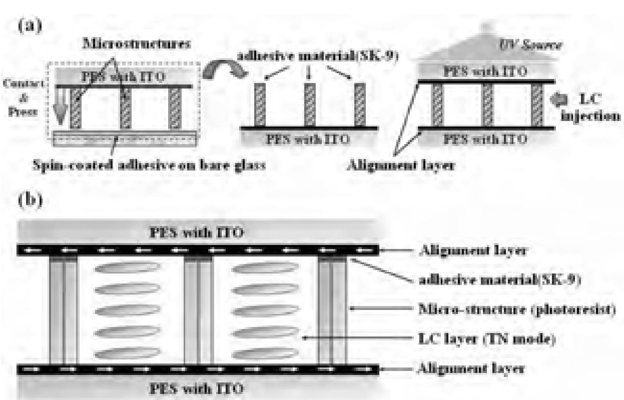

Figure 1. (a) Fabrication procedure of the device using μCP method. (b) Device configuration of flexible LCD mode based on a microstructure.

curable polymer SK-9 (Optical Bond) was placed on top of micro pillar structure by μCP to assemble two substrates as illustrated. 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. A commercial photoresist material SU-8 (Micro-Chem) was used as the columnar spacer. This technology can be used to obtaining stable cell gap for any flexible LCD structure.

To confirm the stability of our suggestion, we demonstrated the basic LC sample as flexible LCD mode. Figure 1 (b) represents the schematic of suggested structures. Two plastic substrates (Poly-ethersufone : PES) are tightly combined by adhesive material on the micro-structures. The pillar structures maintain stable and uniform gap of device through whole area which is similar to the micro-wall structure in previous PILC configuration [2,5]. However in our configuration, unlikely to the PILC case, isolated adhesion concept of assembling technique provides that 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.

In addition, various pillar structure were designed to optimize stable flexible LCD structure. Figure 2 illustrates the configuration of designed rigid columnar spacer. We divided the conventional single

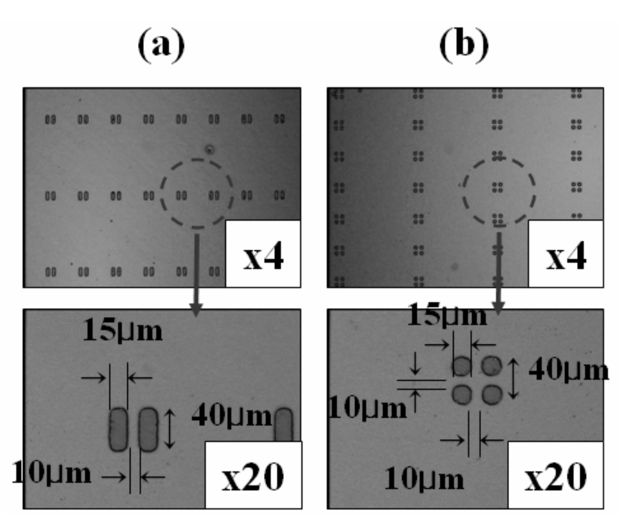

Figure 2. The photographs of designed micro-structure of columnar spacer array. Circled insets in top figures are magnified at the bottom by 5 times (x40 to x200).

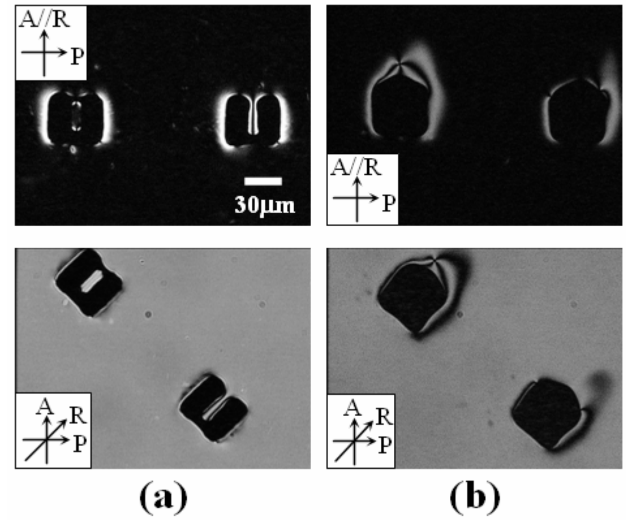

Figure 3. The photographs of LC textures under crossed polarizers around the rigid pillar spacer. Rubbing direction is parallel to the analyzer at the right dark images while that is 45 degree twisted to the analyzer at the left.

pillar structure into the fraction to prevent overflow of adhesion materials and confined excessive agent into the spacer area. Two types of design were demonstrated to check the mechanical stability and overflow effect variation. Figure 2(a) rigid spacer have two pillar structures of 15μm × 40μm with 100μm, 300μm of lateral spacing, while Fig. 2(b) have four columnar structures of 15μm diameter with the same spacing as shown in the figure.

3. Result and Discussion

To compare suggested configuration and conventional electro controlled birefringence (ECB) mode, we demonstrated the basic LC sample by using plastic substrate of PES (polyethersulphone). As described earlier, one of the main advantages of our technique is to be suitable for various LC modes which are essential to establish high quality display while the other LC based flexible techniques have restricted LC mode suitability. In our demonstration, homogeneous LC aligning agent Nylon-6 (Merck) was used and rubbed in an anti-parallel direction to obtain planar LC alignment sample. Nevertheless, as depending on the LC aligning agent and rubbing direction, we can easily realize different LC mode for this system. A commercial nematic LC (ZKC-5085XX from Chisso) was utilized in this study and its birefringence (Δn)

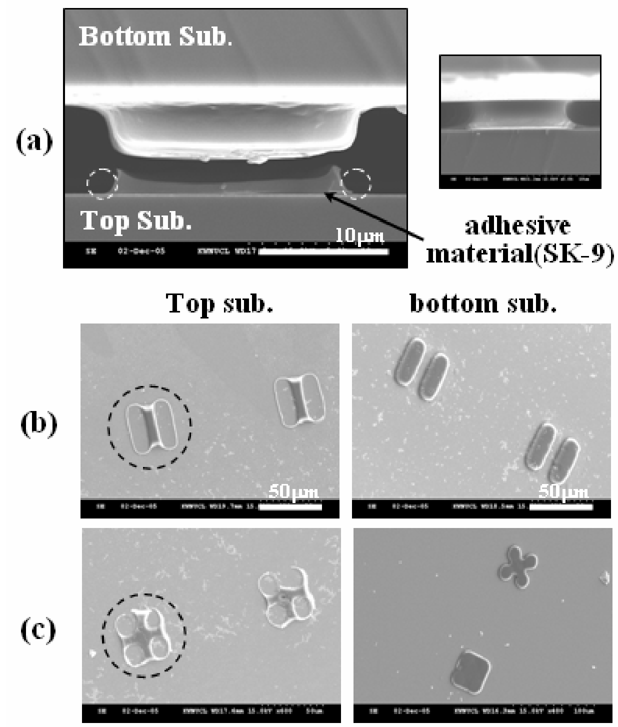

Figure 4. (a) SEM image of cross section after using μCP method. (b) and (c) is top and bottom substrate after detaching sample, respectively.

and $\Delta\varepsilon$ is 0.1515 and 9.57, respectively. The cell gap was maintained as 3μm by rigid photoresist micro-structure.

The clear isolated shaped structure of adhesive material was observed in the texture of LC sample as shown in fig. 3. From the capillary effect, more self-aggregated polymer structure was obtained in the fig. 2(b), which we can expect that this type can be more suitable and effective to show better adhesion properties and maintain stable cell gap against the external distortion. Note that the small boundary effect disturbs LC alignment around the columnar spacer in the figure. More detailed study for surface effect should be performed to reduce the defect structure. Uniform confined structure, however, was obtained through the whole spacer array and this means our process is well established and organized. In addition, as verified by dark and white LC texture change in the figure, stable ECB mode was achieved as we expected.

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). Adhesion material was placed on

(Dimension: N / cm^2)

	1	2	3	4
Fig. 2(a)	**1.89**	**3.38**	**1.89**	**2.36**
Fig. 2(b)	**4.35**	**5.00**	**5.00**	**3.01**

Table 1. Adhesion breaking test by increasing weight of the loads. Sample structure employed as fig. 2(a) and fig. 2(b) by μCP method.

top of micro pillar structure, and confirmed that don't exceed inside pixel boundary by overflow.

Fig. 4(b) and Fig. 4(c) show the SEM images of the top and bottom substrates after opening the cell and removing the LCs in the inter- and intra pixel regions. The area where the adhesive material was attached to the micro pillar structures was obviously observed in the dotted regions of Fig. 4(b) and Fig. 4(c). Same conclusion was confirmed by monitoring LC textures in the Fig. 3 (a) and Fig. 3(b).

In final, 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 result, our samples bear the load about 2.54 and 4.56 N/cm^2, for Fig. 2(a) and Fig. 2(b) type rigid spacer, respectively. This result can be easily understood by matching the LC texture observations and our general expectation from the pillar design. Note that the small boundary effect disturbs LC alignment around the columnar spacer in the figure.

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 the confined structure of adhesive material by capillary effect and μCP bonding supports the good adhesion of two plastic substrates. From various experimental results, we confirmed that much stabilized flexible LCD can be obtained within a simple fabrication procedure. In addition, suggested configuration can easily adopt various LC modes because the control of LC alignment at top substrate is possible, diverse flexible LCD can be realized by using this technique. In conclusion, the micro-structure based flexible LC mode is expected to play a critical role in the practical application for manufacturing flexible display with versatile usage.

5. Acknowledgements
This work was supported by Samsung Elctronics LCD R&D Center and Korea Research Foundation Grant, KRF-2004-005-D00165

6. References
[1] F. Matsumoto, T. Nagata, T. Miyabori, H. Tanaka and S. Tsushima, SID ’93 Dig., 965 (1993).

[2] J.-W. Jung, S.-K. Park, S.-B. Kwon and J.-H Kim, Jpn. J. Appl. Phys., **43**, 4269 (2004).

[3] B. Comiskey, J. D. Albert, H. Yoshizawa and J. Jacobson, Nature, **394**, 253 (1998).

[4] D. Braun and A. J. Heeger, Appl. Phys. Lett., **58** 1982 (1991).

[5] S.-J. Jang, J.-W. Jung, H.-R. Kim, M.Y. Jin and J.-H.Kim, Jpn. J. Appl. Phys., **43**, 6670 (2005).