# P-120: Tight Bonding of Two Plastic Substrates for Flexible LCDs

**Se-Jin Jang[1], Jun-Hyung Kim[1], Ji-Hong Bae[1], Yoonseuk Choi[2], Hak-Rin Kim[3], Sang Il Kim[4], Seongsik Shin[4], and Jae-Hoon Kim[1,2,5,*]**

[1]Department of Information Display Engineering, Hanyang University, Seoul, 133-791, Korea
[2]Research Institute of Information Display, Hanyang University, Seoul, 133-791, Korea
[3]School of Electrical Engineering and Computer Science, Kyungpook a National University, Daegu, 702-701, Korea
[4]Samsung Electronics, LCD R&D Center, Gyeonggi-Do, 449-711, Korea
[5]Department of Electronics and Computer Engineering, Hanyang University, Seoul, 133-791, Korea

## Abstract

*We developed a novel technique to maintain a constant cell gap of the flexible LCD under various external distortions. The two flexible substrates were assembled tightly by the UV curable polymer placed on top of rigid pillar spacer array. In this technique, we designed the columnar micro-structure to lead the self-collected construct of adhesive polymer which promotes the good adhesion and high mechanical stability against the external deformations.*

## 1. Introduction

Flexible display technologies have been extensively studied in the last few years since it offers many advantages and potentials to the various applications. In flexible displays, we can realize the very thin display, ultra light weight, robust system, ability to flex and fold, high-throughput manufacturing and various portable and wearable applications [1]. Among the competitive technologies, the liquid crystal display (LCD) with plastic substrates is the most promising device because of its superior visibility with low power consumption compared to the other displays such as organic light-emitting devices or electrophoretic displays [2-3]. Thus, the researches to achieve a LCD system on the flexible substrate are viably studied to realize the commercial flexible display with a high performance.

One of main issues in these techniques is maintaining constant cell-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 because of intrinsic properties of LC. Although recent effortful developments like pixel isolated liquid crystal (PILC) structure have shown the enhanced mechanical stabilities to an external force, it has remains to be solved limits of the device such as the complex fabrication, the induced defects from polymer wall or residual polymer, and especially the restricted display application range [4-5].

In this paper, we demonstrate the effective technology for obtaining the stable spacing of flexible display using the columnar rigid spacer and the UV curable polymer. The pre-designed pillar spacer array provides the realization of the precise and stable cell gap through whole pixel area 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. Experimental

Fig. 1 (a) shows the schematic illustration of tight bonding process for two flexible substrates with the columnar spacer array and the adhesive material. The rigid spacers maintain stable and uniform gap of device through whole area even when the external deformation is applied to the cell. This is confirmed by our previous study with the PILC configuration by anisotropic phase separation technique [4-5]. With conventional structure of rigid spacers only, however, the tight bonding of two plastic substrates can not be achieved. In order to solve this problem, we can apply UV or thermal curable epoxy on rigid spacer as shown in Fig. 1(b). In this case, however, we can meet overflow of epoxy which degradates image quality of LCD.

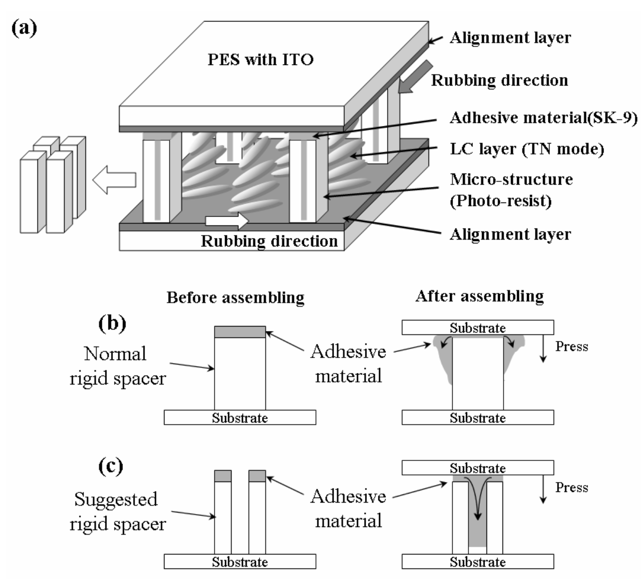


**Figure 1. Schematic illustration of device configuration and pillar rigid spacer. (a) Twisted nematic mode demonstration for flexible LCD by adopting the designed pillar micro-structure and the bonding technique. (b) & (c) are conventional and proposed rigid spacer with UV or thermal curable epoxy, respectively.**

For tight bonding of two flexible substrates, we proposed new shape of rigid spacers with hollow structure to prevent overflow problem as show in Fig. 1(c). In this structure, the epoxy is isolated by capillary force. We fabricated pillar rigid spacers with conventional photo-lithographic technique using commercial photo-resist SU-8 (Micro-Chem). The UV curable epoxy, SK-9 (Optical bond), is printed on rigid spacers using micro contact printing (μCP) [6].

We designed and tested various pillar structures to compare the capillary filling effects and the effectiveness of this technique. We conclude that the micro-structure with four sub-pillars showed the optimized result.

In order to fabricate flexible LCD, homogeneous LC alignment layer AL3045 (Chisso) was used and rubbed in perpendicular direction to obtain twisted LC alignment by using plastic substrate of PES (poly- ethersulphone). As depending on the LC alignment layer and rubbing direction, we can easily realize different LC mode with these rigid spacers. A commercial nematic LC (MJ00993 from Merck) was used in this study and its birefringence (Δn) and the difference of dielectric constant (Δε) is 0.1515 and 11.1, respectively. The cell gap was maintained as 3 μm by rigid photo-resist micro-structure.

## 3. Results and Discussion

The clear isolated structures of adhesive material were observed through the texture of LC sample as shown in the fig. 2. The resultant designed rigid spacer has four columns where the diameter and lateral spacing are 15 μm, 10 μm, respectively. The distance between each pillar was 150 μm. From the results, the

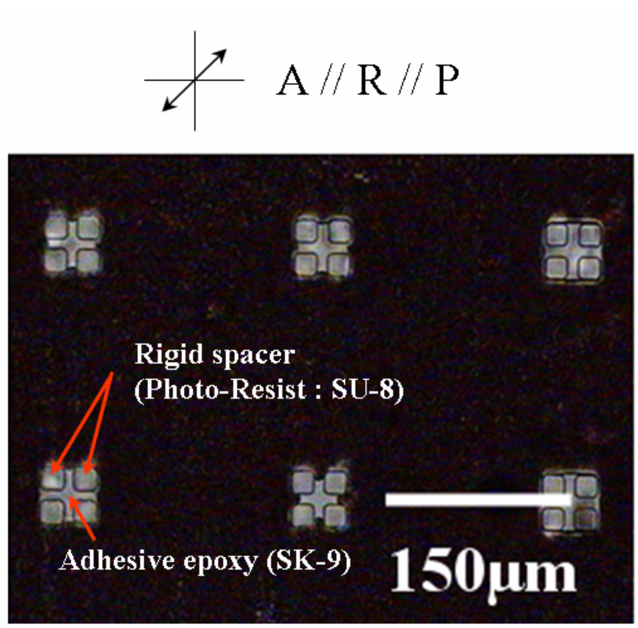


**Figure 2. (a) The photographs of LC textures and micro-structures under parallel polarizer**

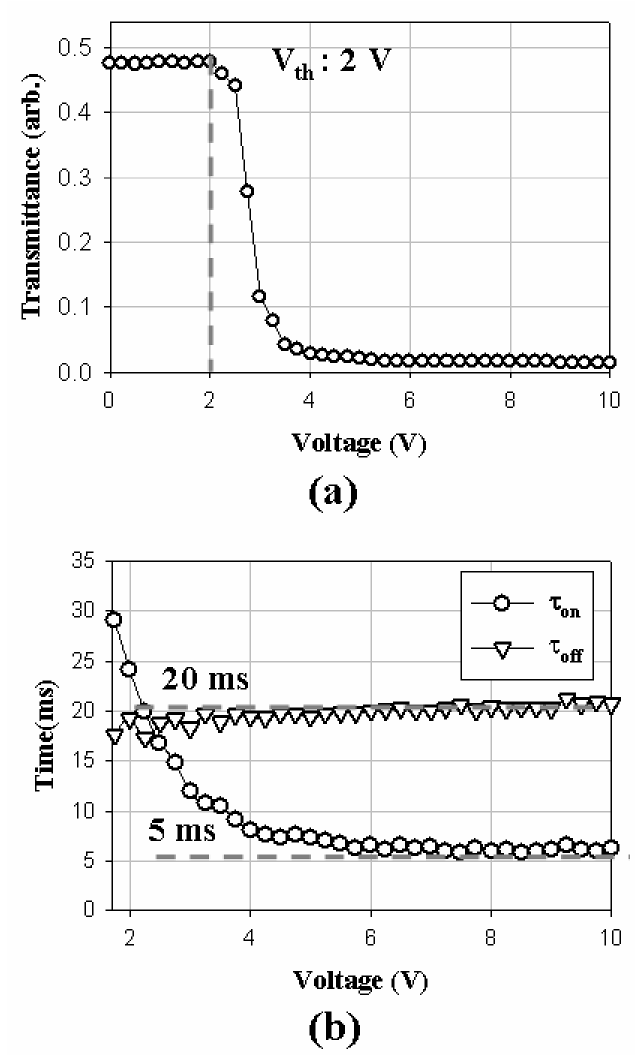


**Figure 3. The electro-optic characteristic of tightly bonded plastic LCD sample by using PES substrates.**

self-aggregated polymer structure was confirmed which can maintain the stable cell gap against the external distortion and hold the upper substrate tightly. Note that the LC alignment is disturbed near the columnar spacer in the figure due to the non-uniform printing of epoxy.

Figures 3(a) and (b) show the electro-optic characteristics of our plastic LCD. The threshold and saturation voltage was 2 V and 6 V, respectively. The contrast ratio is about 100:1. And response time is 25 ms (filed driven and relaxation time is 20 ms, 5 ms, respectively). From the results, we can confirm that the flexible LCD with suggested configuration has similar characteristics as conventional TN mode with glass substrates.

In order to check the bonding strength of the proposed rigid spacers between two plastic substrates, we measured the

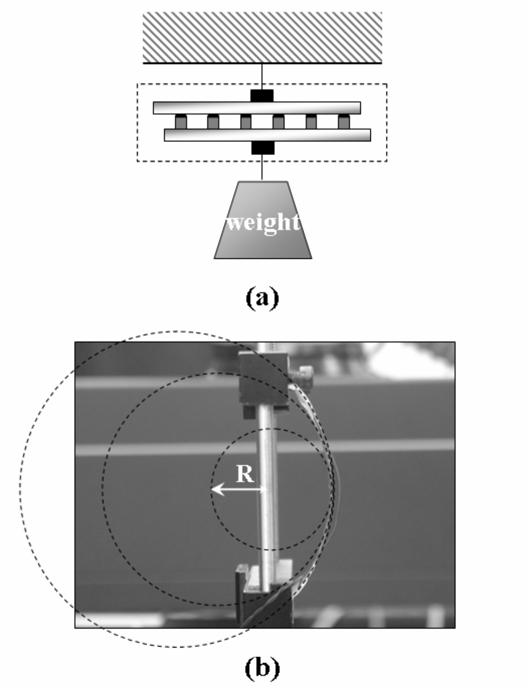


**Figure 4. Experimental setup for mechanical stability. (a) Bonding strength test, (b) Bending deformation test.**

| **R** (Bending Radius) | $\infty$ | 4.6 cm | 3.2 cm | 2.1 cm | 1.5 cm | 0.5 cm |
|---|---|---|---|---|---|---|
| **Type I** | **good** | **good** | **good** | **good** | **Poor** | **break** |
| Type II | good | good | poor | break | - | - |

**Table 1. Bending test as increasing the degree of bending. (R is bending radius). Type I and II are plastic samples based on our tight bonding method, and only pillar structure, respectively. Both samples are treated with the seal line process.**

maximum tension to preserve cell gap of the sample. We fixed one substrate and add weights to the other substrate until the sample took apart as shown in Fig. 4 (a).We carried out the experiment several times and the averaged tension was 4.56 $N/cm^2$. This result can prove tightly bonding of top and bottom substrates.

And also, we measured bending capability of the sample by measuring EO properties with changing degree of bending as shown in Fig. 4(b). From the experiment, our method (Type I) can tolerate even with hard bending of R = 1.5 cm (R is the radius of bending curvature), while the sample with only the micro-structure with seal line (Type II) is broken after engaging bending action of R = 3.2 cm as shown in the table 1 which proves that this technique supports stable cell gap of the device under high external bending forces. From these results, we can conclude that the suggested method can be useful to realize the flexible LCD with reliable device performance.


**Figure 5. The photograph of prototype 3 inch plastic LCD using the proposed technique.**

## 4. Fabrication of 3 inch plastic LCD

Figure 5 shows a 3″ -prototype plastic LCD with the proposed rigid pillar structures. A full color flexible LCD can be achieve by RGB color filter. We demonstrated by laminating patterned color filter sheets on the top substrate. The operating voltage was 6 volt. The response time (field driven + relaxation time) was about 25 ms. The contrast ratio was about 100:1 even in bending distortion. Photograph shows the operation flexible LCD even with severe bending of R = 2.5 cm.

## 5. Conclusion

In conclusion, we have demonstrated the micro-structured flexible LCD based on the designed pillar spacer with the UV curable polymer for bonding. This method prevents overflow of adhesive polymer into the pixel area due to the capillary filling effect of designed pillar spacer. A self-isolated structure of adhesive material guaranteed tight bonding of two plastic substrates. The suggested method can easily adopt various LC modes because the control of LC alignment at top and bottom substrate is possible.

## 6. Acknowledgements

This work was supported by Samsung Elctronics LCD R&D Center and Korea Research Foundation Grant, No. KRF-2004-005-D00165.

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