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# Flexible LCDs with tightly adhesive property using by contact printing method with thermally curable epoxy

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We proposed flexible LCD with good adhesion property by novel adhesion technique using thermally curable epoxy to apply roll-to-roll process in manufacturing of LCDs. Since high viscosity of thermally curable epoxy was controlled by the optimized ratio of THF, the micro contact printing technology with the maximum efficiency could be used to realize the flexible LCD. By the mechanical stability test, we demonstrated mechanically stable flexible LCDs against the physical deformations.

## 1. Introduction

For the last few years, the flexible displays have attracted considerable attention for next-generation displays due to their excellent portability. Among available current competing technologies such as organic light emitting diodes (OLED), electrophoretic display, electrochromic display and electrowetting display, liquid crystal displays (LCDs) constructed by substituting plastic films for conventional glass substrates have great advantages for commercialization of flexible displays due to their full growth of fabrication technology in FPD and their guaranteeing superior visibility with low power consumption [1, 2]. However, flexible LCDs have critical problems which must be overcome for successful commercialization. One of those problems is the instability of LCs alignment at physical deformation such as bending and pressing. The other is the separation of two flexible substrates. Because flexible LCDs always experience bending and folding, it is necessary to find excellent adhesion techniques for the commercialization of the flexible LCDs.

In the early works, adhesion technologies for rugged flexible LCDs were estimated in various methods. For the tight adhesion of two plastic substrates, micro contact printing method with UV curable epoxy was used on multi column rigid spacers for confining the epoxy by the capillary effect [3]. The composite materials of UV curable epoxy as adhesive material and agarose as a container were also used [4]. The composite materials could prevent the leakage of epoxy into the pixel without a design limit of the rigid spacer as well as showing good adhesion. However, it was a limit to use UV curable epoxy in practical manufacturing due to cutting off the UV light by black matrixes (BM).

In the following, micro contact printing method using NOA83H (Norland Co.) with thermally curable epoxy instead of UV curable epoxy will be suggested. High viscosity of thermally curable epoxy which makes uniform micro-contact printing (μCP) on rigid spacers more difficult is controlled with tetrahydrofuran (THF). We present the flexible LCD with tight adhesion property by this method.

## 2. Experimental

Schematic diagram of fabrication procedure is shown in Figure 1. First, both of the ITO-coated PES substrates were spin-coated with a homogeneous alignment layer and anti-parallel rubbed. The rigid spacers of negative photo resist SU-8 were formed on the bottom substrate to maintain the cell gap between two substrates. And then, the mixture of NOA83H as thermally curable epoxy and THF solution with the optimized ratio was transferred to rigid spacers using micro contact printing method (Figure 1(a)).

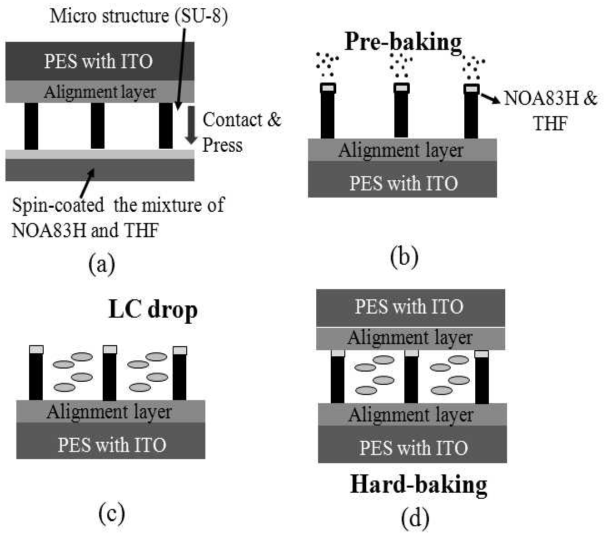


Figure 1. The schematic diagram of fabrication process. (a) micro contact printing process for transfer bonding layer on rigid spacers, (b) pre-baking process on the bottom substrate, (c) one drop filling (ODF) process of LCs and (d) covering the top substrate on rigid spacers and hard-baking process.

Since NOA83H as thermally curable epoxy has high viscosity which makes it difficult to process using micro contact printing method, THF (Tetrahydrofuran) as a solvent with different weight ratio was used. The ratio of thermally curable epoxy to THF was determined by varying from 1:1 to 1:5 to optimize the mixing condition. We progressed the prebaking at 1:3 of the optimized mixing condition. After transferring the bonding mixture by micro contact printing process, for the evaporation of solvent, the sample was prebaked at 80℃/7.6mmHg in vacuum to evaporate THF and change the state of thermally cured polymer in first order hardening state (Figure 1(b)). THF evaporated as well as thermally curable epoxy change from liquid state to a first order hardening state as a result of this pre-baking-process. LCs was filled by ODF process on the transferred mixture and had no reaction with first order hardened thermally curable epoxy (Figure 1(c)). After then, for the second order hardening state, we annealed to 125℃/7.6mmHg in vacuum for 60 min (Fig. 1(d)). By a series of this process, the LC sample for this research could be obtained.

## 3. Result and Discussion

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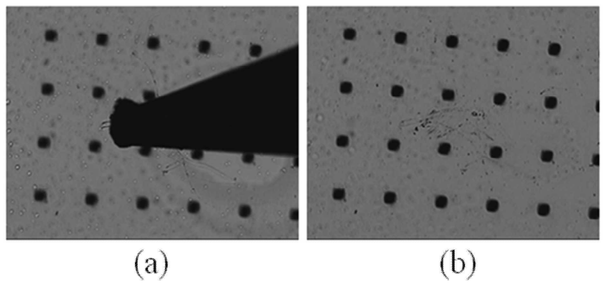


Figure 2. Alignment texture of (a) the condition on pressing with a sharp tip, and (b) the condition after pressure.

We now describe the alignment stability of flexible LCD against external mechanical press. Figure 2 shows alignment texture now and after pressure with sharp tip. When the physical pressure is applied to the sample, we can see the color change due to the reorientation of LC director. However, the alignment is recovered immediately and the alignment texture is exactly same as that of the sample before pressure because LC sample with the vertical rigid spacers is kept LC alignment well against the physical pressure.

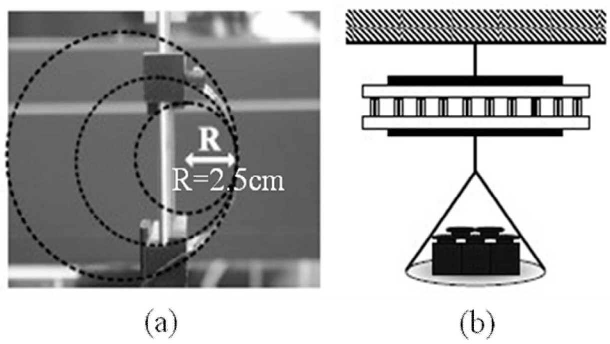


Figure 3. Experimental set up for confirmation of the adhesive property. (a) bending distortion test, (b) bonding strength test.

In order to confirm the tight adhesion between two substrates, the experimental set up showed in figure 3. The bending capability of the sample was measured by changing degree of bending as shown in figure 3(a) until destruction. Our sample could endure even with hard bending of R=2.5cm (R is the radius of bending curvature). We also measured maximum capable loads by increasing the additional loads during preserving the cell gap of the sample (Figure 3(b)). Though severally repeated tests, the averaged value of adhesion property was property was 11.2N/$cm^2$. From these experimental results, flexible LCD with tight adhesion property could be obtained by the micro contact printing method with the mixture of thermally curable epoxy and solvent.

Figure 4 shows electro-optical properties of the TN mode flexible LCD sample by our method. The height of rigid spacers was about 5.5μm and the thickness of contacting mixture was about 2.2μm. We used MAT-03-151(Merck) as LC for birefringence (Δn) and the dielectric constant's difference (Δε) of it was 0.104 and 5.5. That is, we determined the conditions of process to set the Morguin parameter [5]. Our sample has the bright state in the field-off state. As increasing the applied voltages, the texture became darker due to vertical LC reorientation along the field direction. The transmittance-voltage curve of the sample was measured. Our sample has the threshold voltage which is about 1.7V and the saturation voltage of 10V. The measured contrast ratio of the TN mode sample is about 370:1. We can confirm that the flexible LCD by proposed process has similar characteristics to conventional TN mode on glass substrates [6,7].

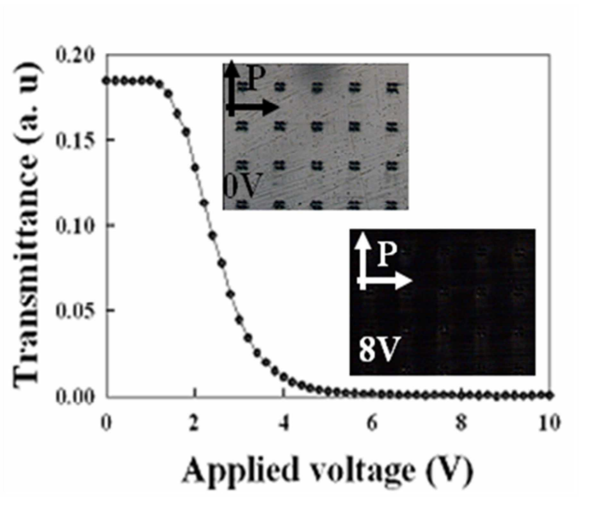


Figure 4. Electro-optical properties; the polarizing microscopic images and transmittance-voltage curve.

## 4. Summary

We proposed the flexible LCD with excellent mixture of proposed the flexible LCD with excellent adhesive properties by the micro contact printing method with the mixture of thermally curable epoxy (NOA83H) and solvent (THF). In the early works, adhesion technologies with the UV curable epoxy were limited in practical manufacturing due to cutting off the UV light by black matrix (BM). By the micro contact printing method with the mixture of NOA83H as thermally curable epoxy and THF as solvent which can be controlled the high viscosity of thermally curable epoxy, we could obtain the flexible LCD with good adhesive properties. Also, the suggested method can reduce the cost of process and make the simple process. The possibility of flexible LCDs manufacturing can be shown in this paper.

## Acknowledgement

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