P-71: Substrate Adhesion Technique using Thermosetting Resin to Apply Roll-to-roll Process to Manufacturing of LCDs

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Abstract

We developed novel substrate adhesion technique using thermosetting resin to apply roll-to-roll process to manufacturing of LCDs. We can use one-drop-filling (ODF) process without any distortion of LC alignment using the mixture of thermosetting resin and tetrahydrofuran(THF). This technique can be used to roll-to-roll process for flexible LCDs.

1. Introduction

The flexible display technology has been extensively studied in the last a few years. Most displaying units such as plasma display panel (PDP), organic light emitting diodes (OLED), electronic-paper (E-paper) are finding the way to overcome a new challenge. There are two indispensable conditions to make flexible LCDs. Developing technology to keep the uniform and stable cell gap against physical deformations is necessary. One of the techniques to solve this issue is rigid spacer made of negative photo-resist using capillary effect [1, 2]. In the next place techniques for enhanced adhesion of the top and bottom substrates against various deformations are required. To commercialize the flexible LCDs, it is necessary to find new adhesion techniques for roll-to-roll process. In the early works, UV curable polymer and agarose mixture was used to bond two substrates [3]. But in this case, the manufacturing processes are complex and not cost-effect. Furthermore, it is easy to use UV curable polymer in practical manufacturing because black matrices (BM) cut off the UV light.

To overcome this problem, we blended new solution using thermosetting resin. However there is a fatal drawback when we use thermosetting resin in LCD manufacturing. High viscosity of thermosetting resin makes uniform micro-contact printing (μCP) on rigid spacers more difficult [4, 5]. Moreover, if we drop LC, it occurs an LC alignment distortion due to reaction between LC and adhesive polymer. To apply roll-to-roll process to LCD manufacturing, one-drop-filling (ODF) injection of LC is required. In this paper, we present the good LC alignment without any distortion around of rigid spacers using mixture of thermosetting resin and tetrahydrofuran(THF).

2. Experimental

The procedures for preparation of flexible LCD are described. First, an LC align polymer (PI) was coated on plastic substrate by spin coating machine. To maintain the cell gap between top substrate and bottom substrate, the rigid spacers made of negative photo resist (PR: SU-8 2005; MicroChem. Co.) were built on bottom substrate. Revolutions per minute (RPM) of spin coating machine is determined by height of rigid spacers [6]. Then

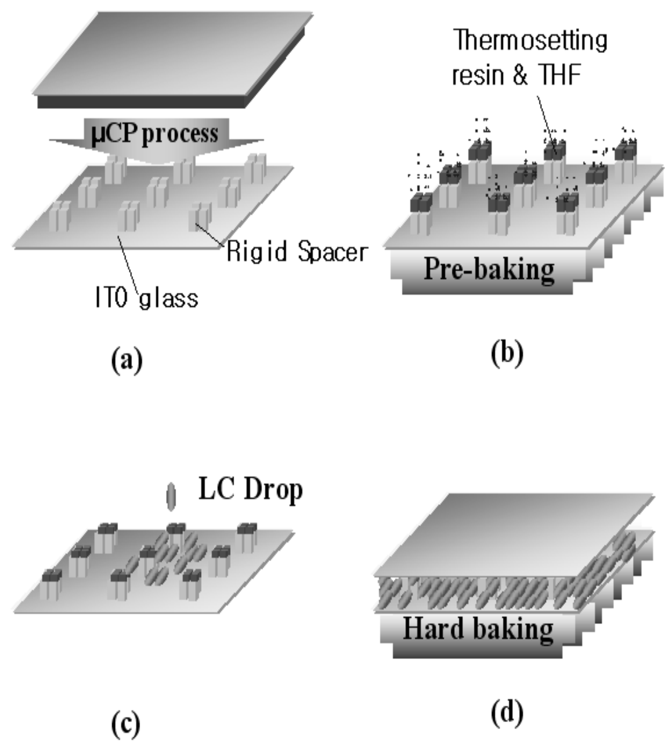
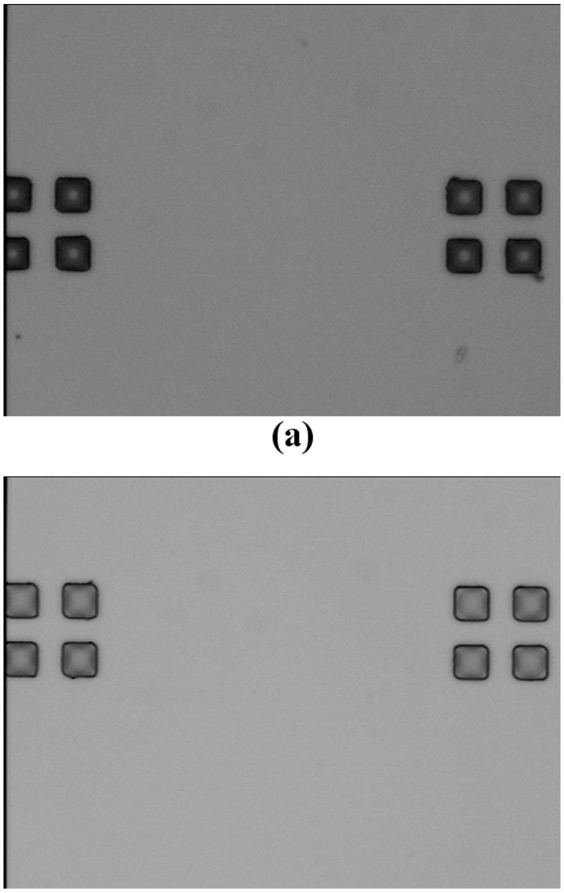


Figure 1. Schematic diagram of manufacturing process. (a) μCP process to transcribe bonding layer on rigid spacers (b) Pre-baking process on bottom substrate (c) One drop filling process of LC (d) Covering the top substrate on rigid spacers and hard-baking process.

the mixture of thermosetting resin (NOA 83H; Norland Product, Inc.) and THF on the rigid spacers by μCP process (Fig. 1(a)) were transcribed. After that, the sample was heated (Fig. 1(b)). We heated the bottom substrate at vacuum with 80℃/7.6mmHg, to evaporate THF and to change the state of thermosetting resin in first order hardening state. THF was removed as well as thermosetting resin pass from a liquid to a first order hardening state as a result of this pre-baking process.

We filled LC by ODF process on the transcribed mixture (Fig. 1(c)). In this process, there was no other reaction between LCs

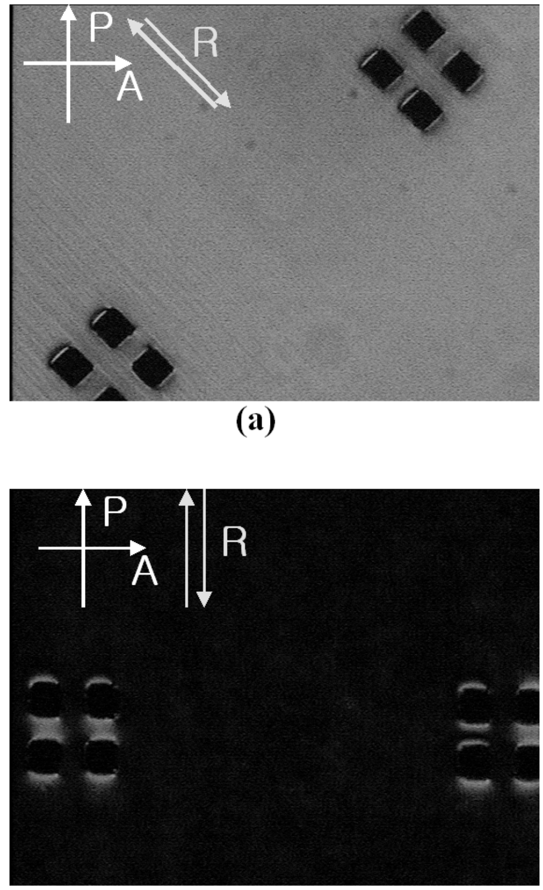
 ISSN/008-0966X/08/3903-1454-$1.00



(a)

(b)

Figure 2. Microscopic images of fabricated cell on plastic substrate. (a) After transcribing the mixture of thermosetting resin and THF mixture onto rigid spacers using μCP method. (b) The reduced area occupied by the mixture after pre-baking process.



(a)

(b)

Figure 3. Polarizing microscopic image of fabricated flexible LCD with ECB mode where P, A and R denote polarizer, analyzer and rubbing direction of top and bottom substrates, respectively. The rubbing directions of the LC alignment layer on the top substrate and bottom substrate are 45^o in (a) and 0^o in (b) with respect to the transmission axis of the polarizers.

and first order hardened thermosetting resin. The sample was annealed at vacuum with 125℃/7.6mmHg for 60 min (Fig. 1(d)).

A series of process is shown in figure 1. The cleaned plastic substrate is used as standard sample in these studies.

3. Results and Discussion

To optimize the sample before pre-baking, the ratio of thermosetting resin to THF was determined between 1:1 to 1:5. The maximum efficiency was obtained at 1:3 (thermosetting resin to THF) and the structure is shown in Figure 2.

To make certain the concept of our experiment, we made the sample with ECB (electrically controlled birefringence) mode. The polarizing microscopic image of ECB mode fabricated on plastic substrate to confirm the alignment of LC molecules is shown in Fig 3. We made the sample adjusted at optical retardation of 3/2λ (λ=632.8 nm). The height of the transcribed mixture of thermosetting resin and THF by μCP process is about 2.2μm. The height of rigid spacers was set to about 8.0 μm by controlling the RPM of spin coating machine. We used the LC MLC-6233-000 (Merck; Δn = 0.0901, Δε = 4.3). JALS-1085-R33(JSR) was used as LC alignment polymer (PI) for homogeneous alignment of LC molecules in our experiment.

Rubbing directions of top and bottom substrates were anti-parallel to each other. We observed the sample under the polarizing microscope. The polarizer and analyzer were perpendicular to each other. When we filled the LCs by ODF process, LCs didn't react with first order hardened thermosetting resin. Although we covered the upper substrate on the bottom substrate, thermosetting resin maintained the shape even after pre-baking process. As shown in figure 3(a), there are the minimum disclinations around the rigid spacers. For that reason, there is the minimum light leakage near the rigid spacers at black state as shown in figure 3(b). In case without pre-baking process, we could observe that the light leakage occurs through not only around the rigid spacers but also inside of the four columns.

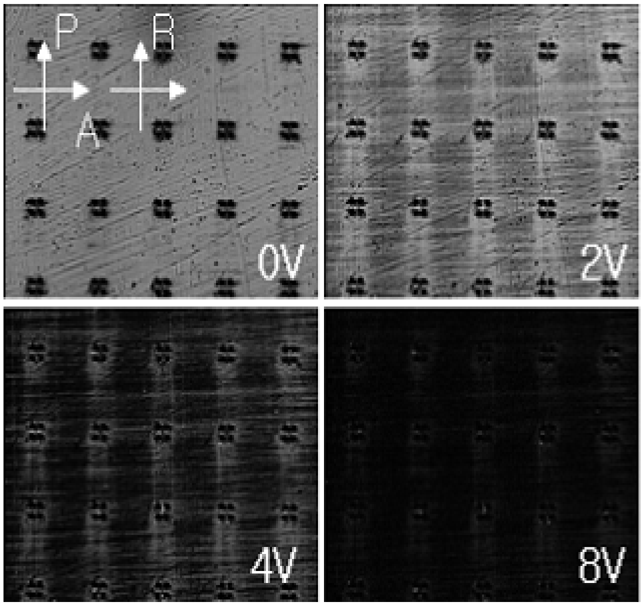


Figure 4. The polarizing microscopic images of fabricated TN mode LCD on plastic substrates as voltages applied where P, A denote the directions of the polarizer axis and analyzer, respectively. R denotes the direction of rubbing process.

Figure 4 shows the polarizing microscopic images of the flexible LCD sample fabricated with TN (Twisted Nematic) mode [7, 8]. The height of rigid spacers and the thickness of contacted mixture were about 5.5 μm and 2.2 μm, respectively. We used MAT-03-151 (Merck), of which birefringence (Δn) and the anisotropic dielectric constant ($\Delta\varepsilon$) were 0.104 and 5.5, respectively. In this case, the optical condition was determined by the second Mauguin condition which leads to waveguiding effect [9]. As shown in Figure 4, the sample shows that as the voltage increased, the sample is getting darker, with white state under the initial no-voltage.

Figure 5 shows the voltage dependent transmittance curve measured in the sample of Figure 4. The threshold voltage is about 1.7V and the saturation voltage is about 10V. The measured contrast ratio of the TN mode sample is about 370:1. We controlled the factors to fit the second Mauguin condition as mentioned. From the results, we can confirm that the flexible LCD with proposed process has similar electro-optic characteristics as compared to the conventional TN mode with glass substrate.

4. Conclusion

We suggested new technique to overcome the several problems when we apply roll-to-roll process to manufacturing of LCDs with thermosetting resin. With our process, we could reduce very high viscosity of thermosetting resin by mixing THF.

For more simple process, we could adopt ODF process of LC without any reactions between contacting polymer and LC molecules, by changing the thermosetting resin into the first order hardening state. As a result, the leakage of light was minimized around the rigid spacers. Because the thermosetting resin shows mightier sticking property than UV curing polymer, the fabricated samples show stronger adhesive power between upper and lower substrate.

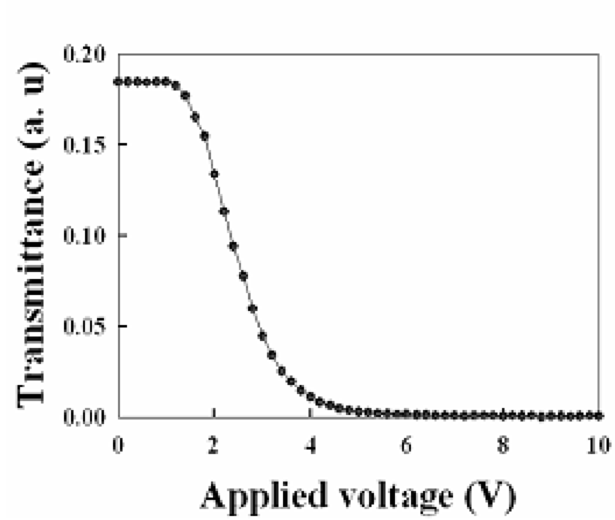


Figure 5. Transmittance-Voltage curve of fabricated TN mode.

Also, because the LCD samples in our experiment were fabricated on plastic substrates, we can expect it is possible to apply our technique to practical process of flexible LCDs directly. The proposed method can reduce the cost of process and make the process simple. We make sure that the characteristics of LCDs are not changed on plastic substrate. In other word, our experiment shows the possibility of flexible LCDs manufacturing.

5. Acknowledgements

This research was supported by Samsung Electronics LCD R&D Center and by one of the 21st century Frontier R&D programs funded by the Ministry of Commerce, Industry and Energy of the Korean government.

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