Stamping Method for Fabrication of Flexible Liquid Crystal Display

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Abstract

We proposed a new fabrication method for stable flexible LCDs using stamping method with durable elastomer such as poly(dimethylsiloxane) (PDMS). In the device, the LC molecules are isolated in pixels where LCs are surrounded by PDMS microstructure, and two substrates are tightly attached by phase separated polymer layer. The electro-optic characteristics of our cell are comparable to those of normal sample without PDMS microstructure. We propose cost-effective roll-to-roll process for large size of plastic LCDs with our method.

1. Introduction

Recently, flexible liquid crystal displays (LCDs), which use plastic films substituting for conventional glass substrate, opened up new application areas of LCDs such as smart cards and rollable displays. Moreover, it is expected that such plastic LCD will replace conventional glass substrate-based LCD in the mobile display applications due to its light weight and thin packaging properties[1-3]. However, there are some problems for current plastic LCDs to be commercialized. Since plastic substrates can not sustain uniform cell gap condition, the LC alignment is easily deformed by external pressures. To enhance LC stability, flexible LCDs require cell gap-sustaining structures which should be distributed in the whole area of plastic substrate. In conventional approaches, the stability of the plastic LCDs was achieved by polymerized networks. But, such method requires several steps of photo-masking process[4] or high electric field treatment to get patterned polymer wall structures, which are not proper for manufacturing.

In this presentation, we propose a new fabrication method for enhancing the stability of flexible LCDs using stamping method with durable elastomer such as poly(dimethyl-siloxane) (PDMS). In our structure, LC molecules are isolated into each pixel by the stamped polymer wall structures. Since such stamping method can be applied to roll-to-roll processing, it is expected that cost-effective mass production of large size of flexible LCDs is available with the method presented here.

2. Pixel Isolation by Stamped Polymer Walls

Figure 1 shows the schematic illustration of our fabrication process. The first step of Fig. 1(a) was to produce a master structure using photoresist SU-8 (Micro-Chem) by normal photolithographic method. The master substrate had an inverse structure to final polymer wall structure. The second step was pattern-transferring process using PDMS. Onto the master substrate, liquid PDMS was dropped and the excess liquid PDMS was wiped out by a PDMS block as shown in Fig. 1 (b). The PDMS wall structure produced by the patterned master structure can be effectively transferred to the covered bare ITO substrate by heating under pressure as shown in Fig. 1 (c). Under pressing the covered ITO glass, the cell was baked 100? °C for 10 min. Then, the glass with

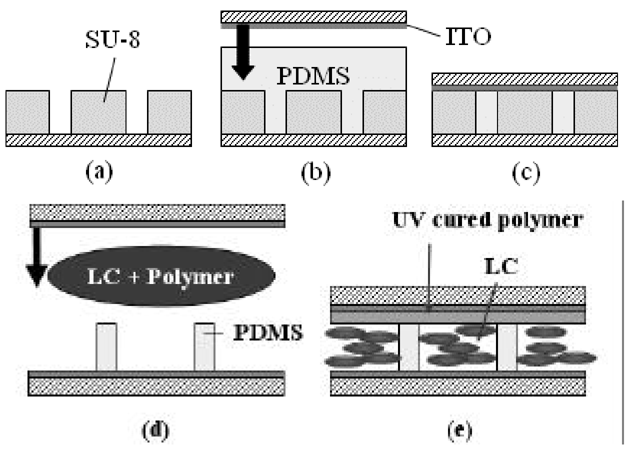
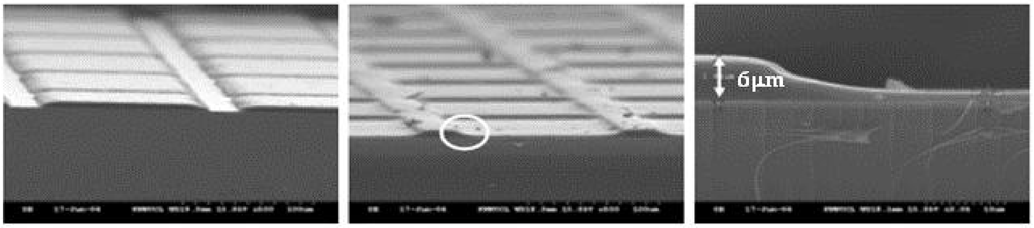


Fig.1. Schematic illustration of the fabrication process: (a) master structure using SU-8 photoresist, (b) & (c) pattern transferring steps, (d) LC cell fabrication, and (e) the cross section of LC cell after UV exposure.



(a) (b) (c)

Fig. 2. SEM images: (a) master structure of SU-8, (b) PDMS after pattern-transferring, and (c) magnification of circular region of (b).

PDMS was separated from the patterned SU-8 structure. By peeling off the master substrate, the bottom substrate with the PDMS wall structures was prepared. Since PDMS provides very low interfacial free energy and good chemical stability, the master substrate can be easily detached without severe degradation of the micro-structure on both substrates[5]. In our experiment, tens of trials could be successfully executed. The next step was preparation of LC cell. To get a homogeneous LC alignment, an alignment layer was spin-coated onto the bottom substrate with the PDMS microstructure as shown in Fig. 1 (d) and the coated surface was rubbed in a direction. As a material to be filled into the prepared cavity, a mixture of nematic LC (NLC), E7 (E. Merck) and UV curable polymer, NOA 65 (Norland Co.) was prepared with the weight ratio of 95:5, respectively. After dropping the NLC/prepolymer mixture onto the micro-patterned substrate and covering another bare ITO substrate as shown in Fig. 1 (d), UV light of ? = 350 nm was irradiated onto the bare ITO substrate to initiate polymerization. The source of UV light was a Xenon lamp operated at 200 W of electrical power. Due to weak UV irradiation condition and high UV absorption in the LC molecules, there exists high UV intensity gradient within our cell and the resultant polymerization takes place mainly near the bare ITO substrate. Thus, the LC molecules are expelled from the polymerized volume, and the prepolymers diffuse to the top substrate forming thin polymer layer as shown in Fig.1 (e).[5-7] Finally the LC molecules are isolated in the pixel surrounded by the PDMS wall structure and the solidified thin polymer layer. The micro-patterned PDMS walls act as supporting structures from external shock. Moreover, two substrates are tightly attached each other by the UV cured polymers.

Figures 2 (a) and (b) are SEM images of the SU-8 and PDMS microstructures, respectively. The width and height of SU-8 microstructure are 300 μm and 6μm, respectively. Figure 2 (c) is magnified image of circular region in Fig. 2(b). It is clear that the patterned structure of SU-8 was well transferred to PDMS structure.

3. Electro-Optic properties

The microscopic textures of our cell under the polarizing microscope are shown in Fig. 3. Figure 3

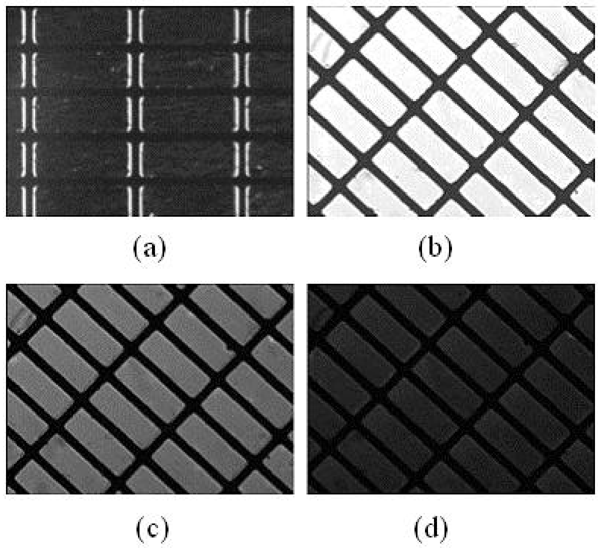
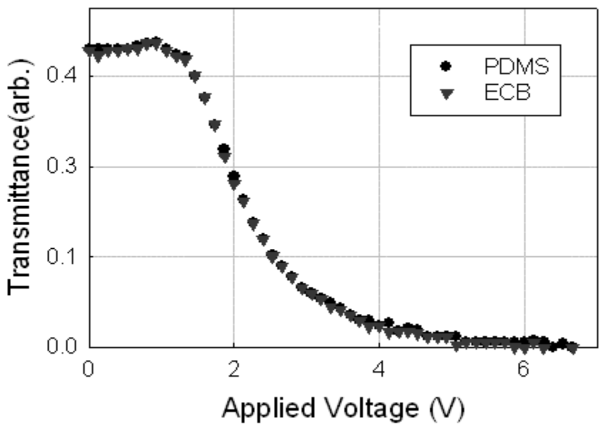
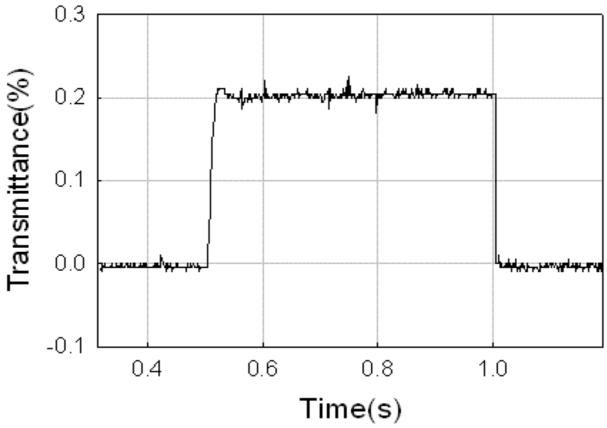


Fig. 3. Microscopic textures under polarizing microscope: (a) is taken when the rubbing direction of the sample is parallel to one of the polarizers. (b), (c), and (d) are taken when the rubbing direction of the sample is rotated by 45 ° with respect to the polarizer in the presence of applied voltages by 0 V, 3 V, and 6 V, respectively.



(a)



(b)

Fig. 4. Electro-optic properties: (a) Transmittance as a function of applied voltages, (b) dynamic behavior.

(a) was taken when the rubbing direction of the bottom surface of the sample was parallel to one of the polarizers and Figs. 3 (b), (c), and (d) were taken when the rubbing direction was rotated by 45 ° with respect to the polarizer in the presence of applied voltages by 0V, 3V, and 6V, respectively. Slight light leakage in Fig. 3 (a) represents the PDMS wall surface has weak LC anchoring. However, overall transmittance behaviour in the pixel area did not be affected in the whole range of applied voltages, as shown in Figs. 3 (b), (c), and (d).

Figure 4 shows the EO properties of our plastic LC device. The transmittance of our cell as a function of an applied voltage from 0 V to 7 V had the same behaviour with that of normal LC sample. Thus, the proposed pixel-isolation method can be easily applied to several types of plastic LC devices without varying the EO properties of normal LC devices. The contrast ratio and the response time were about 100:1 and 27 ms, respectively, which were comparable to those of normal samples.

4. Concluding Remarks

We successfully fabricated a stable flexible LCD using stamping method with durable elastomer of PDMS. Since the LCs were isolated and the substrates were sustained by the stamped polymer walls, our structure provided very stable LC structure against mechanical bending and/or pressure. Tight binding between the top and bottom plastic substrates was achieved by the solidified polymer layer. The electro-optic characteristics of our sample were almost the same as those of a normal LC structure. Since the stamping method can be applied to continuous roll-to-roll processing as shown in Fig. 5, it is expected that

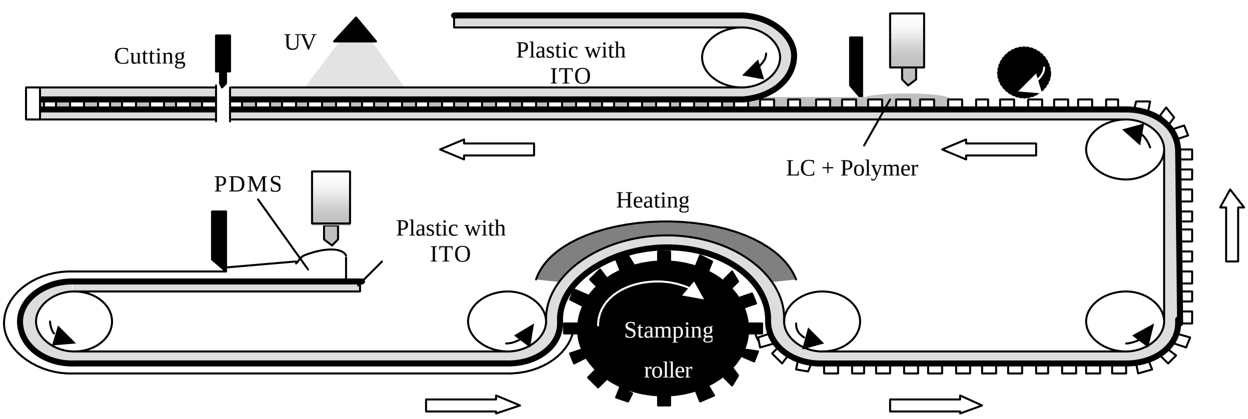


Fig. 5. Schematic diagram of roll-to-roll processing.

large size plastic LCDs with good mechanical stability as well as superior visibility can be cost-effectively fabricated by our method presented here.

4. Acknowledgements

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