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Stability-Enhanced Liquid Crystal Mode for Flexible Display Applications

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Abstract

We demonstrated stability-enhanced liquid crystal (LC) displays using pixel-isolated LC mode in which LC molecules are isolated in pixel by horizontal polymer layer and vertical polymer wall. The device shows good electro-optic properties against external point or bending pressure due to the polymer structures. The polymer wall acts as supporting structure from mechanical pressure and prevents the cell gap from bending. Moreover, the polymer layer acts as an adhesive to ensure a tight attachment of the two substrates. We present herein various methods for producing polymer structures by using an anisotropic phase separation from LC and polymer composites or patterned micro-structures for stable flexible liquid crystal displays.

Keywords : flexible liquid crystal display, phase separation, patterned micro-structure

1. Introduction

Liquid crystals (LCs) have been extensively studied and used for display applications because of their efficient light-control capabilities with low power consumption [1]. These advantages are derived from hydrodynamic properties and high birefringence of LCs. In general, LC devices are prepared by sandwiching LC molecules between two glass substrates with transparent electrodes and alignment layers to obtain a specific configuration of the optic axis. One of the primary roles of these substrates is supporting the LC molecular orientation from external bending or pressure, which are known to cause degradation to the arrangement of LC molecules and to the optical properties of the device.

In recent years, LC devices using plastic film substrates have drawn much attention for use in applications such as smart cards, PDA, and head mount displays because of their lightness, thin packaging, flexibility, and lower manufacturing cost through continuous roll processing [2-4]. However, fabrication of LC displays (LCDs) with plastic substrates raises two major problems; (i) plastic substrates can not give a solid mechanical support for the molecular alignment of LCs between them, (ii) two plastic substrates are easily detached by bending.

To overcome these problems, polymer walls and/or networks as supporting structures have been proposed and demonstrated [5-7]. These structures were fabricated using an anisotropic phase separation method from polymer and LC composite systems by applying patterned electric field or spatially modulated UV intensity. However, these methods require high electric field to initiate the anisotropic phase separation or to keep the residual polymers in an unexposed region that reduce optical properties and increase the operating voltage of the device.

In this presentation, we proposed new methods to produce stability-enhanced LC mode that is suitable for mass production of LCDs with plastic substrates through continuous roll processing.

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2. Experimental Results

We fabricated stability-enhanced LC devices by forming inter-pixel walls produced by various methods such as photo-polymerization induced anisotropic phase separation, photolithography using photo-resist, or stamping method using poly(dimethylsiloxane) (PDMS).

2.1 Pixel-Isolated LC Mode

We fabricated pixel-isolated liquid crystal (PILC) mode with plastic substrates using anisotropic phase separation from LC and polymer composites. ITO-coated poly-ether-sulfone (PES) films were used as substrates. For the alignment layers, we used RN1199 polyimide (Nissan Chemical). The alignment layers were spin coated on one substrate followed by rubbing to achieve homogeneous LC alignment. From the results, we observed that phase separation is greatly affected by alignment layer and prepolymer. The other substrate was untreated to enhance anisotropic phase separation. The cell gap was maintained using glass spacers of 3.5 μm. A mixture of nematic LC (LC17) and photo-curable pre-polymer NOA65 (Norland Co.) of weight ratio of 75:25 was introduced into the cell by capillary action at a temperature higher than the clearing point of the LC. The cells were exposed to UV light of λ = 350 nm to initiate polymerization. The source of UV light was a Xenon lamp operated at 200 W of electrical power. The photomask was placed on one of glass substrates without the alignment layer. The cell with the LC/ prepolymer mixture was irradiated with UV light for about 90 minutes. A second exposure was performed without the mask for 10 minutes to fully harden the polymer. During the second polymerization process, the LC molecules that remained in the polymer network after the first UV exposure were expelled from the polymerized volume. During these first and second UV exposures, the anisotropic phase separation occured in the horizontal and vertical direction, respectively, forming vertical polymer walls and planar polymer layers. Fig. 1 shows the resultant element after UV exposure. The LC molecules can be seen to be isolated in the pixel, surrounded by polymer wall which acted as supporting structures against external shock and, as a result, maintained the cell gap from bending. Moreover, two substrates were tightly attached each other by polymer layer.

Fig. 2 shows the cross section images of PILC cell using scanning electron microscope (SEM). It is clear that the polymer wall is formed between two substrates by the first UV exposure. The residual pre-polymers are completely expelled from the bulk LC layer by second UV exposure forming thin polymer layer onto the bare ITO-coated PES substrate. Due to this second step of UV exposure, our PILC mode can show the good electro-optic (EO) properties and the enhanced mechanical stability with good adhesion of the plastic substrates and the polymer walls.

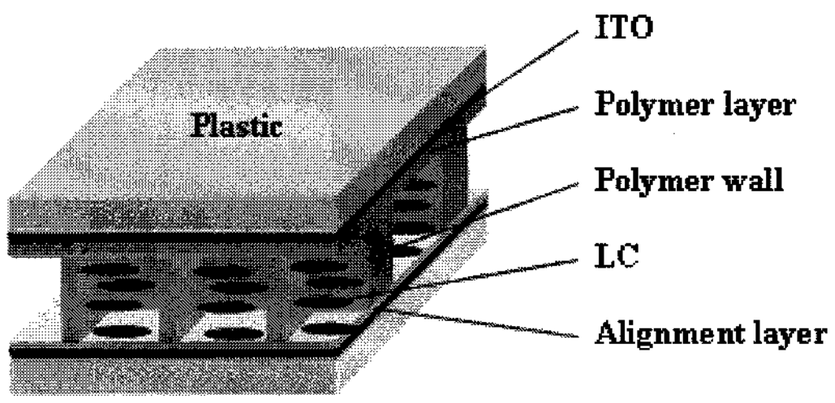


Fig. 1. Schematic diagram of PILC structure.

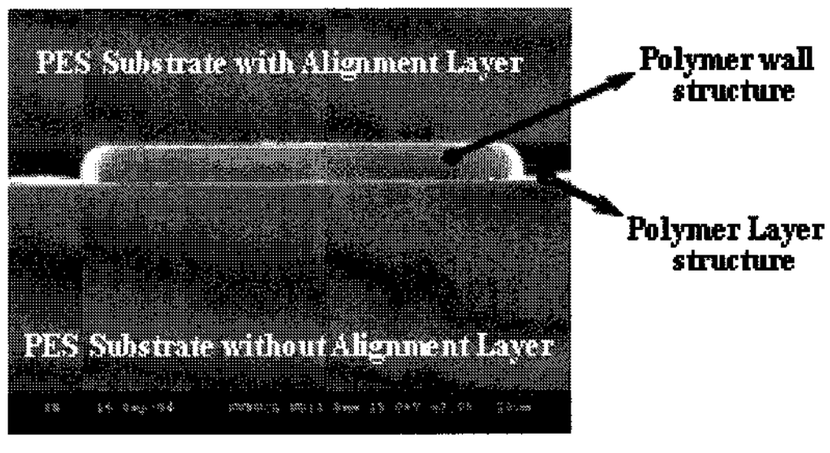
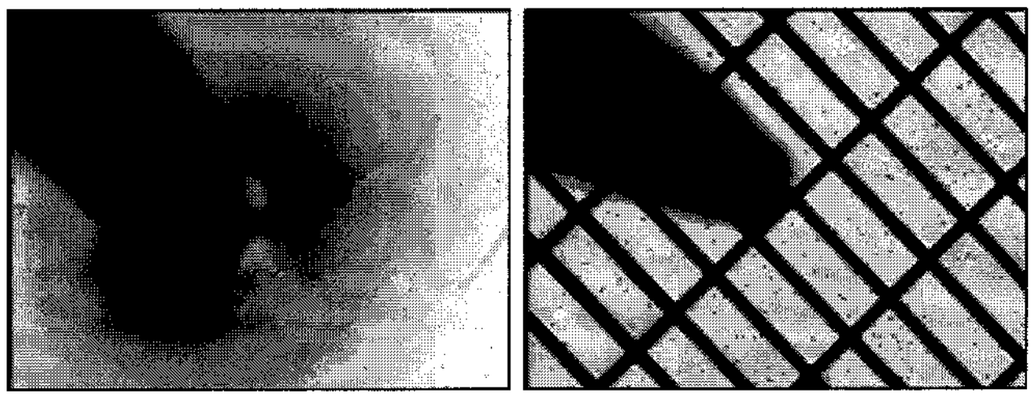


Fig. 2. Cross-sectional image of PILC sample under scanning electron microscope.



(a) (b)

Fig. 3. Alignment textures of (a) a normal and (b) a PILC sample fabricated using plastic substrates. The polarizing microscopic textures were taken in the presence of an external point pressure with a sharp tip.

We tested the mechanical stability of PILC cell against an external pressure and bending. Fig. 3 shows polarizing microscopic textures of a normal and PILC samples with plastic substrates in the presence of an external point pressure by a sharp tip. The alignment texture of the normal sample was severely degraded by the distortion of LC alignment due to the cell gap variation in a relatively large area as shown in Fig. 3 (a). However, that of the PILC sample showed no appreciable changes since the LC

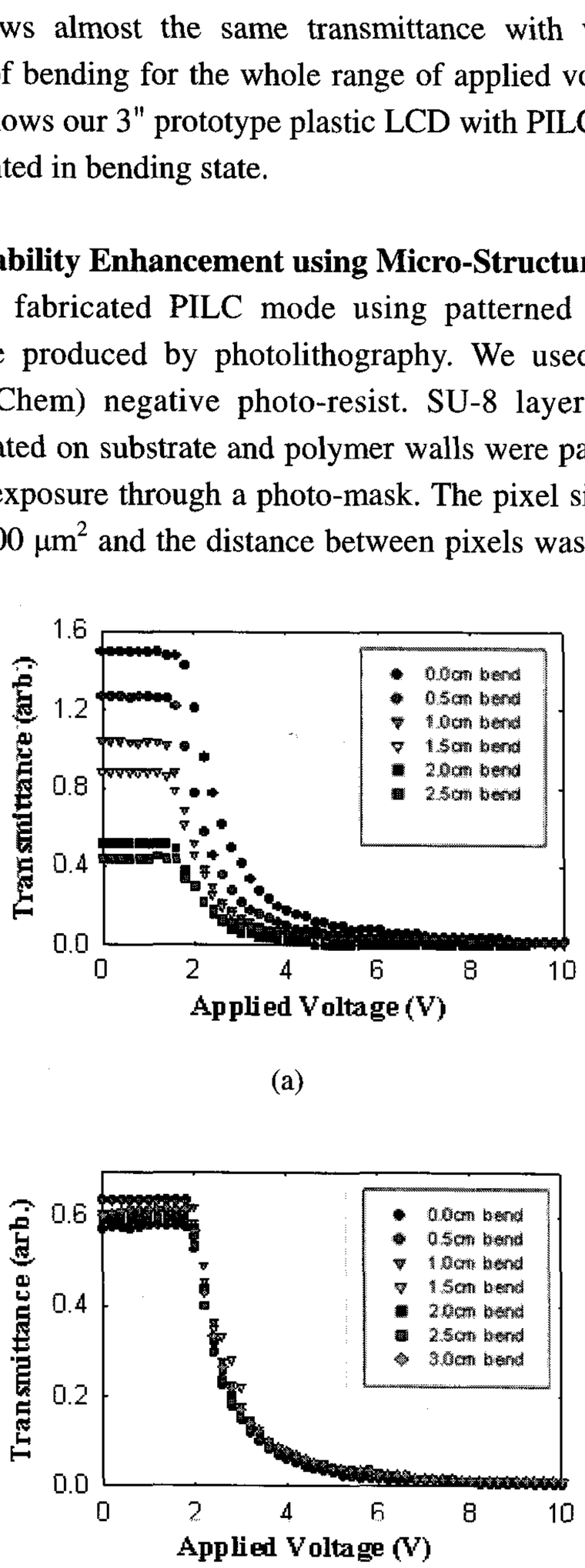
molecular reorientation was restricted and the cell gap were sustained by the polymer wall structure indicated by the dark lines in Fig. 3 (b).

Fig. 4 shows the EO properties of a normal and a PILC cell with an external bending as a function of applied voltage. When the bending stress was applied on normal plastic LC cell, the transmittances starts to decrease with the increase of the degree of bending. However, our PILC cell shows almost the same transmittance with various degree of bending for the whole range of applied voltages. Fig. 5 shows our 3" prototype plastic LCD with PILC mode is presented in bending state.

2.2 Stability Enhancement using Micro-Structure

We fabricated PILC mode using patterned micro-structure produced by photolithography. We used SU-8 (Micro-Chem) negative photo-resist. SU-8 layers were spun coated on substrate and polymer walls were patterned by UV exposure through a photo-mask. The pixel size was 100 x 300 μm^2 and the distance between pixels was 20 μm (Fig. 6 (a)). The alignment layers were spin coated on the micro-structure followed by rubbing to achieve homogeneous LC alignment. In order to attach two substrates, we used anisotropic phase separation [5]. The materials used were E7 (Merck) for nematic LC and UV curable epoxy NOA-65 for prepolymer. A solution of the LC and prepolymer with weight ratio 95:5 was dropped on the microstructure and covered by bare ITO substrate. The cell gap was maintained by the height of microstructure. In our case, we controlled the cell gap to about 6 μm (Fig. 6 (b)).

The cells were exposed to UV light of λ = 350 nm to initiate polymerization. The source of UV light was a Xenon lamp operated at 200 W of electrical power. The UV exposure was exposed onto the bare ITO substrate without micro-structure. Due to the surface wetting property and UV intensity gradient, NOA 65 molecules had to undergo polymerization near the top substrate first and then the LC molecules were expelled from the polymerized volume, forcing them to diffuse away from the UV source [8, 9]. As a result, uniform polymer layer was formed and tightly attached to the two substrates as shown in Fig. 7 (a). Figs. 7 (b) and (c) show SEM images of the cross section of the cell and the surface after top substrates were removed. It

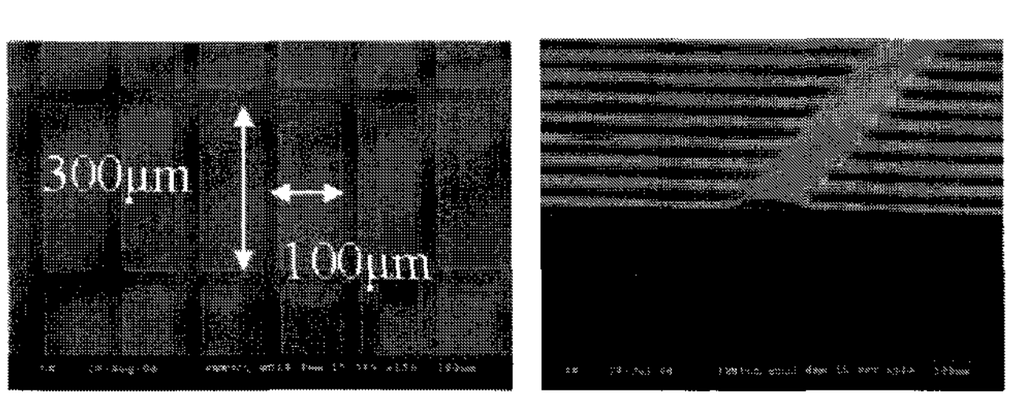


(a)

(b)

Fig. 4. EO properties of (a) a normal and (b) a PILC sample depending on degree of bending.

Fig. 5. 3" Plastic LCD sample using PILC mode.



(a) (b)

Fig. 6. The SEM images of the patterned micro-structures : (a) top view and (b) side view.

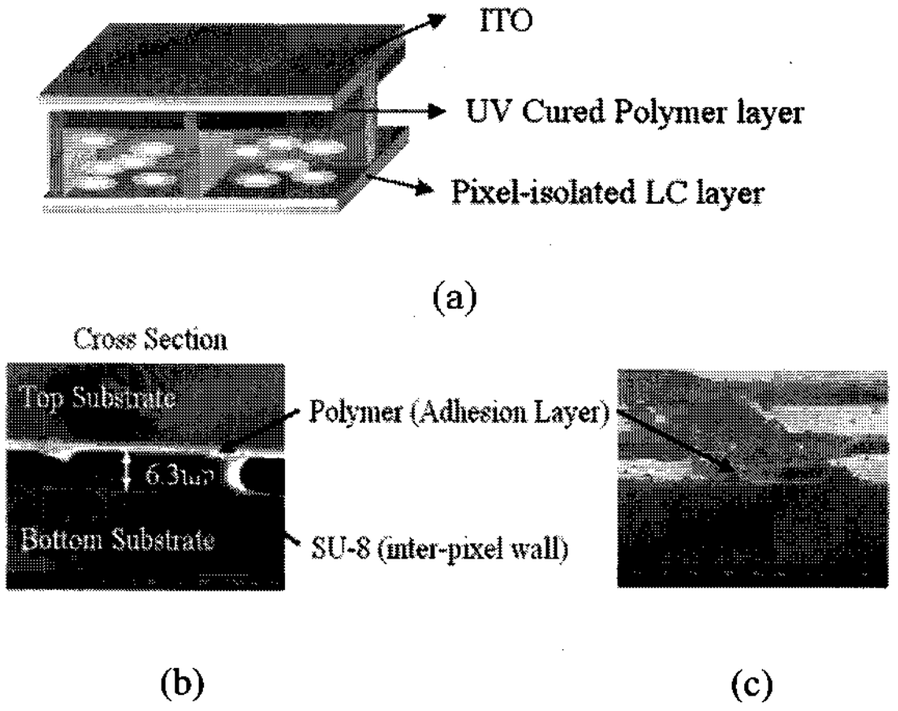


Fig. 7. (a) The schematic diagram of the pixel-isolated LC device using microstructure. (b) SEM image of cross-sectional view and (c) side view after opening the cell.

can be clearly observed that the place of tear-off polymer layer at the attached point. The LC molecules were successfully isolated into the pixel surrounded by microstructure and solidified polymer layer. And the solidified polymer layer caused the micro-structure to become tightly attached to the top substrate.

3. Stamping Method for Micro-Structure

We fabricated micro-structure using stamping method which is applicable to mass production of plastic LCDs through continuous roll processing. Fig.8 shows the fabrication process. In the first step, a master structure is produced using SU-8 photo-resist by normal photolitho-graphic method (Fig. 8 (a)). The second step is pattern-transferring process to PDMS by stamping. The PDMS is coated on a patterned SU-8 structure and covered by bare ITO glass (Fig. 8(b)). After pressing the ITO glass, the cell is baked 100 °C for 10 min (Fig. 8 (c)). Then the glass with PDMS is separated from the patterned SU-8 structure. In the third step, LC cell is prepared. The alignment layers are spin coated on the PDMS microstructure followed by rubbing to achieve homogeneous LC alignment. In this study, the materials used in fabrication of LC cell were E7 for nematic LC and UV curable epoxy NOA-65 for prepolymer. A solution of the LC and prepolymer mixture with weight ratio of 95:5 was dropped on PDMS and covered by bare ITO glass (Fig. 8 (d)). The cell was

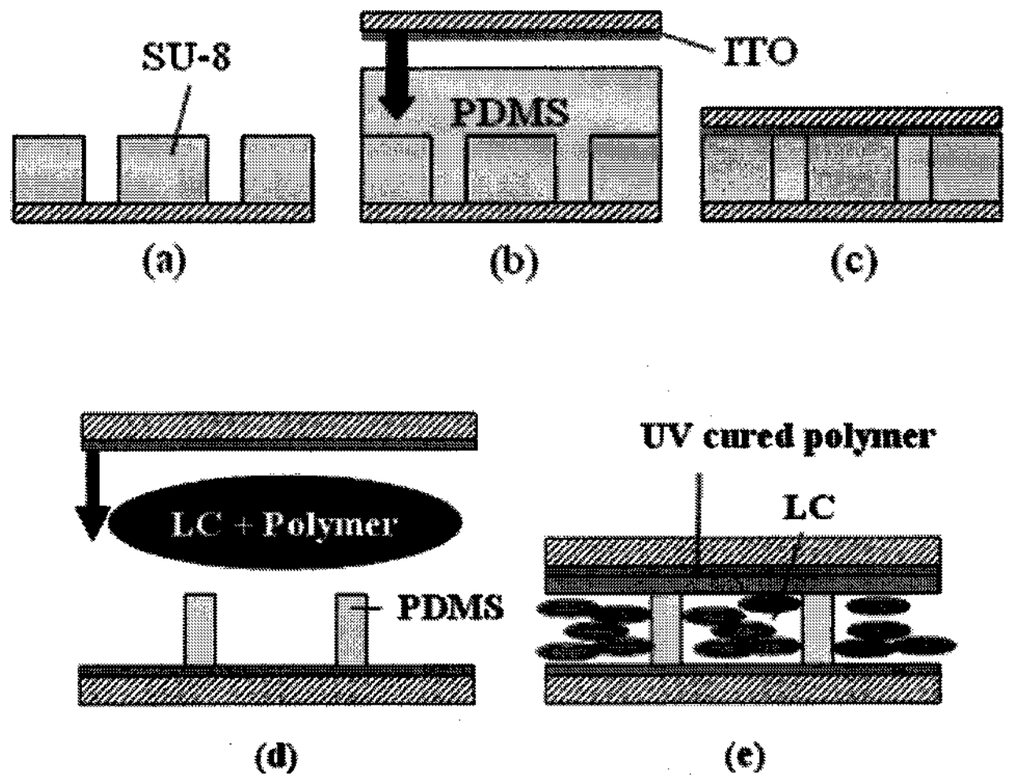


Fig. 8. Schematic illustration of the fabrication process: (a) master structure using SU-8 photo-resist, (b) & (c) pattern transferring step, (d) LC cell fabrication, (e) structure of LC cell after UV exposure.

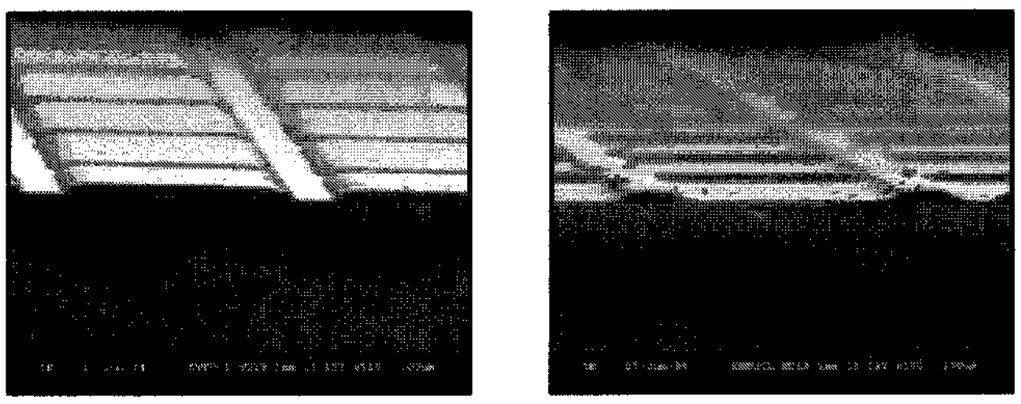


Fig. 9. (a) Master structure of SU-8 and (b) PDMS structure after pattern-transferring.

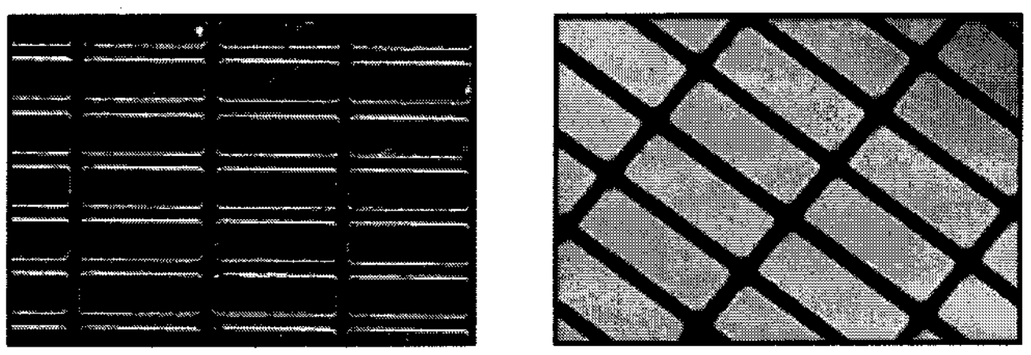
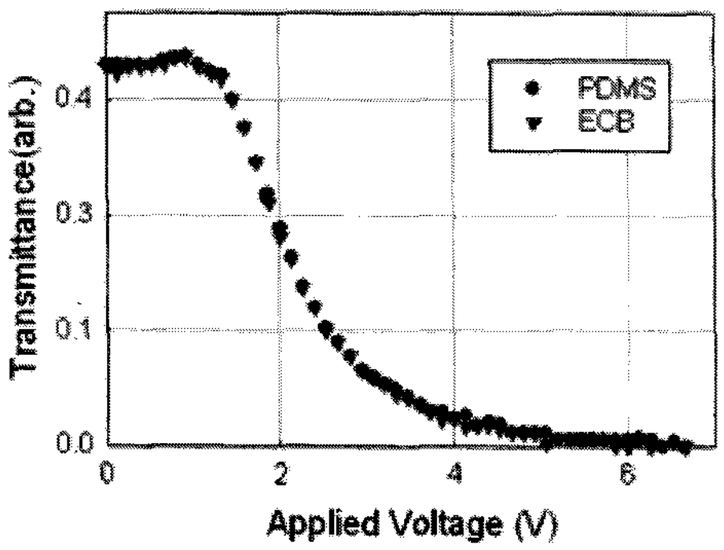
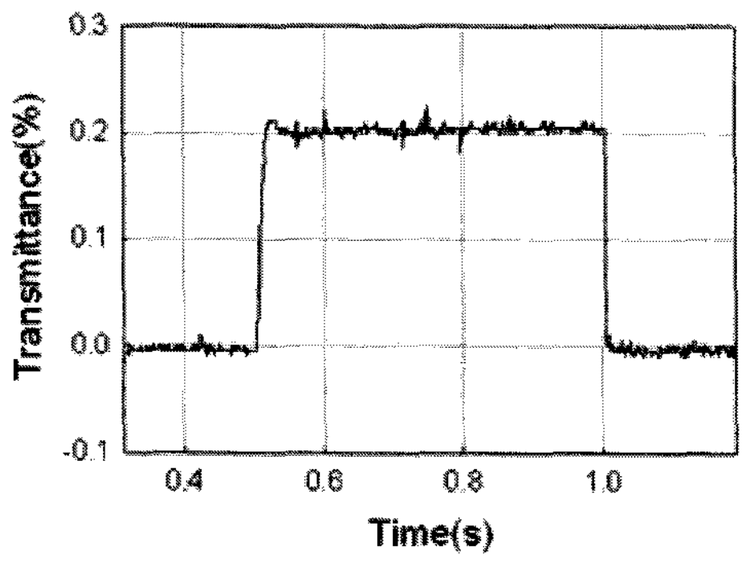


Fig. 10. Microscopic textures of PDMS sample under polarizing microscope: (a) black and (b) white state.

exposed to UV light onto the bare ITO substrates to initiate polymerization. Fig.8 (e) shows the resultant cell structure after UV exposure. The LC molecules are isolated in the



(a)



(b)

Fig. 11. EO properties: (a) Transmittances as a function of an applied voltage of normal and PDMS sample, and (b) dynamic behavior of PDMS sample.

pixel surrounded by PDMS which acts as a supporting structure from external shock. Moreover, two substrates are attached each other by UV cured polymer.

Figs. 9 (a) and (b) are SEM images of the SU-8 and PDMS microstructures, respectively. The width and height of SU-8 microstructure is 300 μm and 6 μm, respectively. It is clear that the patterned structure of SU-8 was properly transferred to PDMS.

Figs. 10 (a) and (b) show the microscopic textures of the cell in black and white state, respectively. The light leakage in black state is due to the distortion of molecular alignment on PDMA wall. Fig.11 shows EO properties for normal and PDMS samples. In both samples, transmittance as a function of applied voltage shows almost the same behavior (Fig. 11 (a)). The dynamic property of PDMS is also the same as that of normal sample as shown in Fig. 11 (b). The measured response time (field driven + relaxation time) is about 20 ms.

4. Concluding Remarks

Mechanical stability is a key issue in the application of flexible LCDs using plastic substrates. In this study, we presented stability-enhanced LCDs using PILC mode in which LC molecules were isolated in pixel by both horizontal polymer layer and vertical polymer wall. The device shows good EO properties against external pressure and bending that are exerted and caused, respectively, by the polymer structures. The polymer wall acts as supporting structure from mechanical pressure and maintains the cell gap from bending. Moreover, the polymer layer acts as adhesive for tight attachment of two substrates. The polymer structures were fabricated by anisotropic phase separation from LC/polymer composites, micro-structures by photolithography, and stamping method. Among these methods, the micro-structure using stamping method is the most appropriate to be used in the mass production of plastic LCDs through continuous roll processing as shown in Fig. 12.

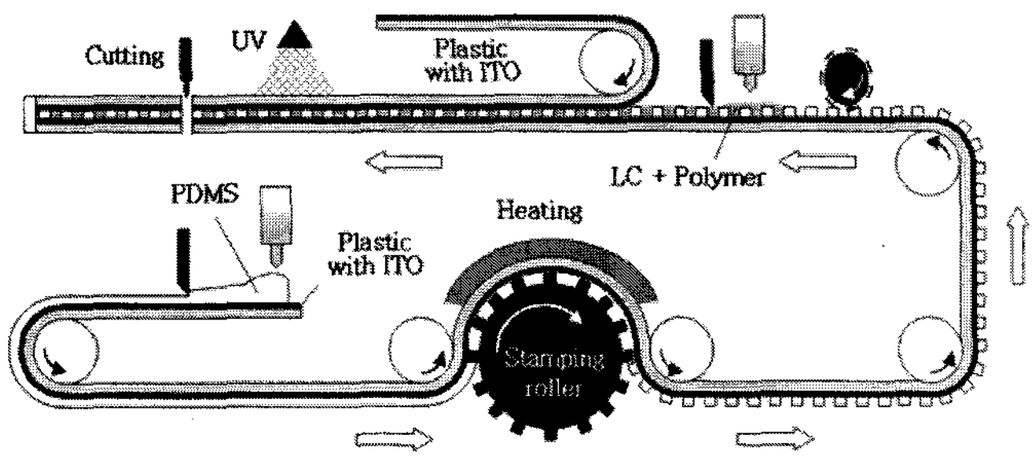


Fig. 12. Schematic diagram of the continuous roll processing for fabrication of the plastic LCDs with the methods presented here.

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