P-103: Fabrication of Stable Liquid-Crystal Structure for Flexible Display Applications

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Abstract

We developed a method for the fabrication of stable pixel structure for flexible liquid crystal (LC) display applications. In the device, the LC molecules are isolated in pixels where LCs are surrounded by patterned microstructures, and two substrates are tightly attached each other by the solidified polymer layer produced by photo-induced anisotropic phase separation. The microstructure can be achieved by general photolithographic method or stamping method with durable elastomer such as poly(dimethylsiloxane) (PDMS). These devices show very good mechanical stability against external pressure.

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. These advantages come 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 primary role of these substrates is supporting the LC molecular orientation from external bending or pressure, which alters the arrangement of LC molecules and diminishes the optical properties of the device.

Recently plastic LCDs have drawn much attention for next-generation information displays because of their excellent portability such as light weight, thin packaging, and flexibility[1-3]. However, there are problems for fabrication of the commercially available plastic LCDs with current technologies obtained from the development of LCDs with glass substrates. One is unstable LC structures due to hydrodynamic properties of LCs at bending and the other is separation of two plastic substrates due to the flexibility of the substrates.

To solve these problems, several types of polymer wall and/or networks as supporting structures have been proposed and demonstrated[4-7]. 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[5] or remain residual polymers in an unexposed region that reduce optical properties and increase the operating voltage of the device[8]. Moreover, these methods are not appropriate to a cost-effective roll-to-roll process, which is essential to fabricate large area plastic LCDs. Thus, an alternate fabrication method should be developed for the plastic LCDs to be commercialized.

In this work, we propose a new method to enhance the mechanical stability in the plastic LCDs using a solidified polymer layer with the patterned wall structures. Such polymer layer is formed by an anisotropic phase separation in the vertical direction of the cell[9, 10], thus the complete phase separation from the polymer-LC composite can be achieved showing almost same optical behaviour with respect to normal LC modes without the wall structures. In addition, this paper provides a stamping method for fabricating the pixel-isolating wall structures using durable elastomers such as poly(dimethylsiloxane) (PDMS), which can be applicable to the roll-to-roll processing for mass production of large size flexible LCDs.

2. Anisotropic Phase Separation Method for Adhesion of Two Substrates

The microstructure is fabricated on glass substrate with ITO by normal photolithographic method using negative photo resist SU-8. Fig. 1(a) shows SEM images of the microstructure where polymer walls are patterned by UV exposure through a photomask. The pixel size is 100 μm x 300 μm and the distance between pixels is 20 μm. The alignment layers are spin coated on the microstructure followed by rubbing to achieve homogeneous LC alignment. The materials used are E7 (Merck) for nematic LC and UV curable epoxy NOA-65 (Norland) for prepolymer. A solution of the LC and prepolymer with weight ratio of 95:5 is 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 as 5.4 μm. The cells are exposed to UV light of $\lambda = 350$ nm to initiate polymerization. The

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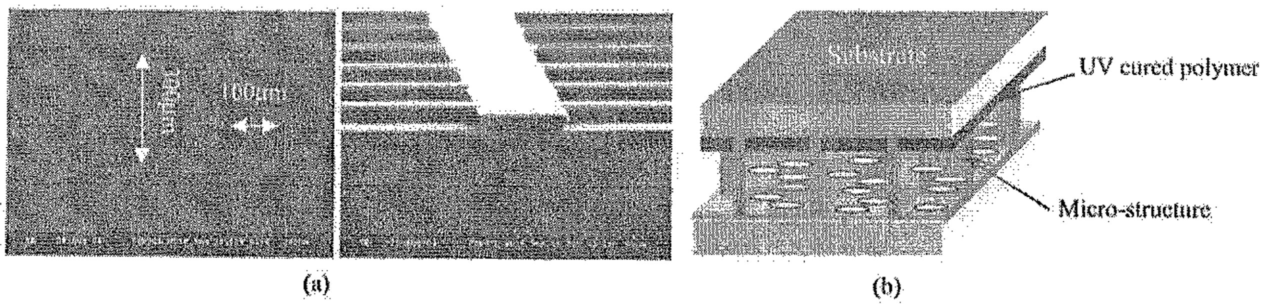

Fig. 1. (a) SEM images of the microstructures (b) Schematic diagrams of the resultant structure after UV exposure.

source of UV light is a Xenon lamp operated at 200 W of electrical power. Because of the absorption of the UV light predominantly by the LC molecules in the solution, an intensity gradient is produced in the sample[9]. Consequently, NOA-65 molecules first undergo polymerization near the UV source and LC molecules are expelled from the polymerized volume, forcing them to move away from the source. As a result, the LC molecules are isolated into the pixel surrounded by microstructure and solidified polymer layer as shown in Fig. 1(b). In the structure, the SU-8 microstructures act as supporting structures from external shock. And the solidified polymer layer tightly attached the microstructure to the top substrate.

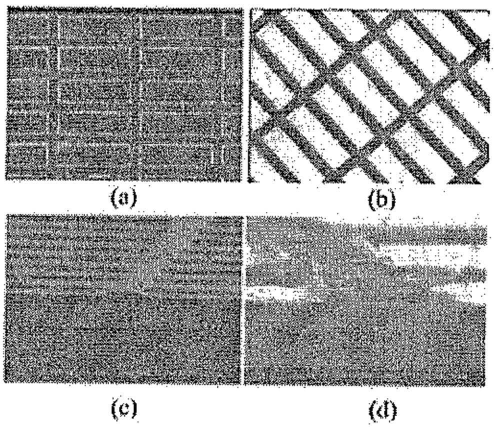

Fig. 2. Microscopic textures : (a) black and (b) white state. SEM images : (c) bottom and (d) top substrate.

Fig. 2 shows microscopic textures at room temperature after UV exposure under polarizing microscope and SEM images after opening the cell and removing LC. It is clear that the LC is confined into the pixels and surrounded by microstructures. The light leakage from the edge in the black state is due to the distortion of molecular alignment on polymer wall. The bottom and top substrates shows patterned microstructures and solidified polymer layer, respectively. It is clear that the polymer layer tear off at the attached point with microstructure in (d).

3. Stamping Method for Pixel Isolation in the Plastic LCDs

The adhesion technique with microstructure in previous section is not applicable to continuous roll-to-roll processing. In this section we propose a method to make stable plastic LCD by combination of stamping method for microstructure and ansirotropic phase separation for adhesion of two substrates.

The pixel-isolating wall structures are fabricated by stamping method using durable elastomeric poly(dimethylsiloxane) (PDMS), which can be applicable to the roll-to-roll processing for mass production of large size flexible LCDs.

Fig. 3 shows the schematic illustration of procedures for fabricating our plastic LC device with the microtransfer molding method. The first step of Fig. 3 (a) is to produce a master structure using the photo-resist SU-8 by the photolithographic method. Onto the master substrate, liquid PDMS is dropped and the excess liquid PDMS is removed as shown in Fig. 3 (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. 3 (c). In our experiment, the heating condition for transferring and solidifying the PDMS structure was 100 °C for 10 min. By peeling off the master substrate, the bottom substrate with the PDMS wall structures is prepared. Since PDMS provides very low interfacial free energy and chemical stability, the master substrate can be easily detached without degradation of the micro-structure on both substrates[11] .

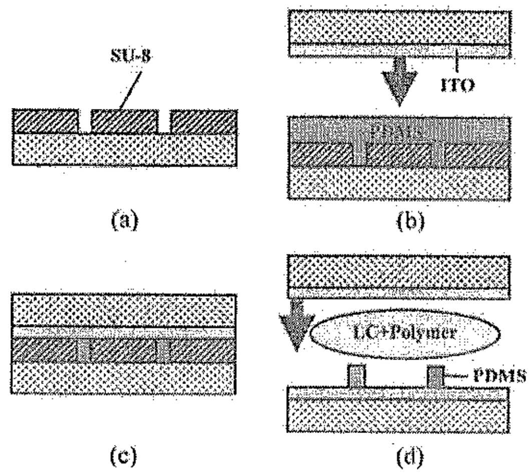

Fig. 3. Schematic illustration of the fabrication process: (a) Master structure using SU-8 photoresist, (b) & (c) pattern transferring step, and (d) LC cell fabrication process.

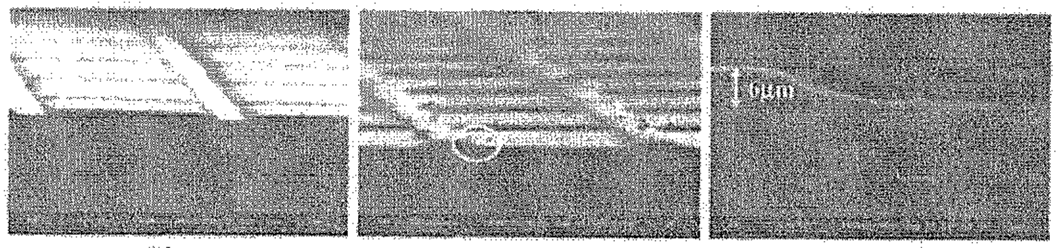

Fig. 4. SEM images: (a) master structure of SU-8, (b) PDMS after pattern transferring, (c) magnification of circular region in (b).

Onto the prepared bottom substrate shown in Fig. 3 (d), a homogeneous alignment layer RN1286 (Nissan) is spin-coated and rubbed to promote uniform LC alignment. After the mechanical rubbing process, the PDMS walls kept initial micro-patterned structures and strongly attached to the ITO surface. The forth step is preparation of LC cell. The materials used are E48 (Merck) for nematic LC and UV curable epoxy NOA-72 (Norland) for prepolymer. A solution of the LC and prepolymer with the weight ratio of 95:5 was dropped on the substrate with the micro-structure and covered by a bare ITO-deposited substrate as shown in Fig. 3 (d). The UV light is exposed from the bare ITO substrate. The solidified polymer layer makes the patterned wall structures strongly attach to the opposite substrate and enhances the mechanical strength of the pixel-isolated LC device as shown in Fig. 1(b).

Fig. 4 (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. Fig. 4 (c) is magnified image of circular region in Fig. 4(b). It is clear that the patterned structure of SU-8 is well transferred to PDMS.

Fig. 5 (a) and (b) show microscopic textures of the cell in black and white state, respectively. Fig. 5 (c) and (d) are show microscopic textures of the cell with various applied voltages. The light leakage in black state is due to the distortion of molecular alignment on PDMA wall. However, overall transmittance behaviour in the pixel area does not be affected in the whole range of applied voltages.

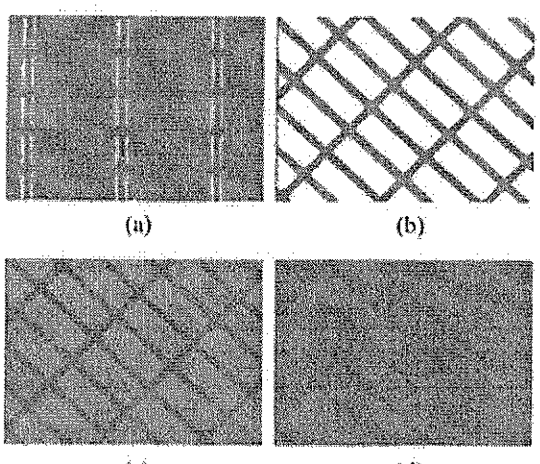

Fig. 5. Microscopic textures under polarizing microscope: (a) black state and white state with (b) 0V, (c) 3V, and (d) 6V.

Fig. 6 shows electro-optic behaviour of normal and PDMS samples. In both samples, transmittance as a function of applied voltage shows almost same behavior. The contrast ratio and response time (on+off) are about 100:1 and 27ms, respectively, which are comparable to normal sample without PDMS.

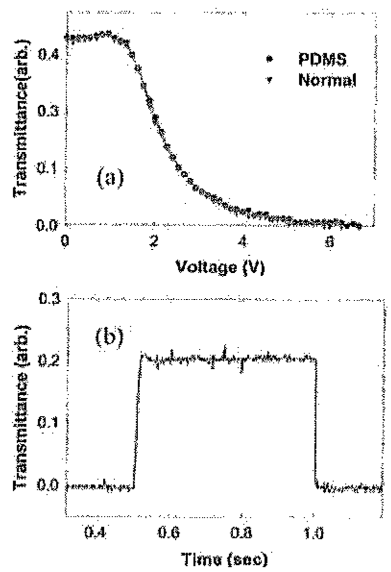

Fig. 6. Electro-optic properties: (a) Transmittance as a function of applied voltage, (b) dynamic behavior.

Fig. 7 shows the schematic diagram for roll-to-roll processing with proposed stamping method. With the stamping roller, the micro-wall structures can be easily produced. After dropping polymer/LC composite onto the bottom substrate with micro-structure and assembling the top and bottom flexible substrates in continuous process, the tight adhesion of two substrates can be achieved by the solidified polymer layer produced by UV exposure.

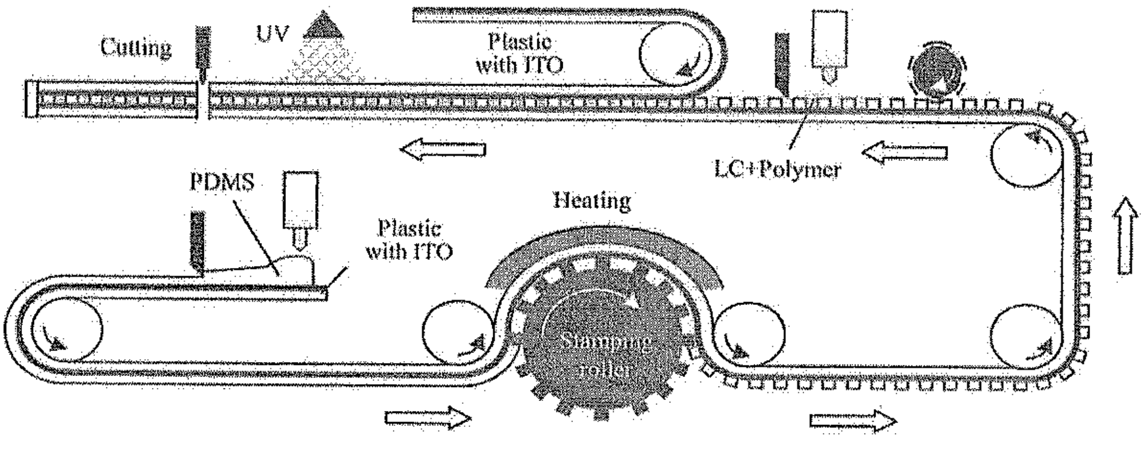

Fig. 7. Schematic diagram for roll-to-roll processing

4. Concluding Remarks

We successfully fabricated plastic LCDs with the stamped polymer wall structure and the phase-separated polymer layer. The stable LC structure could be achieved by isolating LC molecules into the pixel surrounded by the micro-patterned PDMS wall structures. Using the interfacial properties of PDMS, such pixel-isolating wall structures could be fabricated onto one of the substrates easily and repeatedly with the same master substrate. Conventional binding problem between two substrates was solved by the solidified polymer layer which could be uniformly produced using anisotropic phase separation from polymer/LC composite. Experimental results showed that our device had almost same EO properties with respect to normal LC modes without micro-wall structures. It is expected that our proposed methods are applicable to fabricating large size plastic LCDs with good mechanical stability as well as superior visibility through the cost-effective roll-to-roll processing.

5. Acknowledgements

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6. References

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