O7 Flexible Liquid Crystal Display with Micro-structures

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We developed a fabrication method 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 a solidified polymer layer produced by photo-induced anisotropic phase separation. The microstructure can be achieved by general photolithography method or stamping method with durable elastomer such as poly(dimethylsiloxane) (PDMS). These devices show very good mechanical stability against external pressure.

1. Introduction

Recently, LCD, OLED and E-Ink display which use plastic films substituting for conventional glass substrate, have opened up new application area of flexible display such as smart card, e-paper and rollable displays. Among these devices, 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, plastic LCDs give rise to two big problems which do net exist with glass substrates. One is unstable LC structures due to hydrodynamic properties of LC, and the other is separation of two plastic substrates due to the flexibility of substrates. In order to overcome the first problem, polymer wall and/or network as supporting structure have been proposed and demonstrated [4]-[6]. But, those methods require high electric field to initiate the anisotropic phase separation or there exist residual polymers in unexposed region which reduce optical properties and increase operating voltage of the device. The tight attachment of two substrates can be achieved by using spacers with resin. However, the aggregation of spacers due to the resin and weak adhesion still remain to solve. 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 presentation, we propose a new method to solve the above problems, i.e. method for tight adhesion of two substrates with stable LC structure, using patterned microstructure and LC/polymer composite materials. In addition, this paper provides a stamping method for fabricating the pixel-isolating wall structures using durable elastomer such as poly(dimethyl-siloxane) (PDMS), which is applicable to the roll-to-roll processing for mass production of large size flexible LCDs.

2. Method for tight adhesion of two substrates using anisotropic phase separation

Figure 1 (a) is the schematic diagram of the proposed structure of pixel-isolated LC devices. The microstructure was fabricated on bottom glass substrate with ITO by normal photolithography method using negative photo resist SU-8 (Micro-Chem). Figure 1 (b)~(C) shows scanning electron microscopy (SEM) images of the microstructure where polymer walls were patterned by UV exposure through a photo-mask.

The pixel size is 100 μm x 300 μm and the distance between pixels is 30 μm. For the alignment layers, we used 2 wt% Nylon 6 (Aldrich) solution, that were spin coated on the micro-structure followed by rubbing to achieve homogeneous LC alignment. The materials used for nematic LC (NLC) and UV curable polymer were E7 (Merck) and NOA-65 (Norland), respectively. A solution of the LC and pre-polymer with weight ratio of 95:5 was dropped on the microstructure

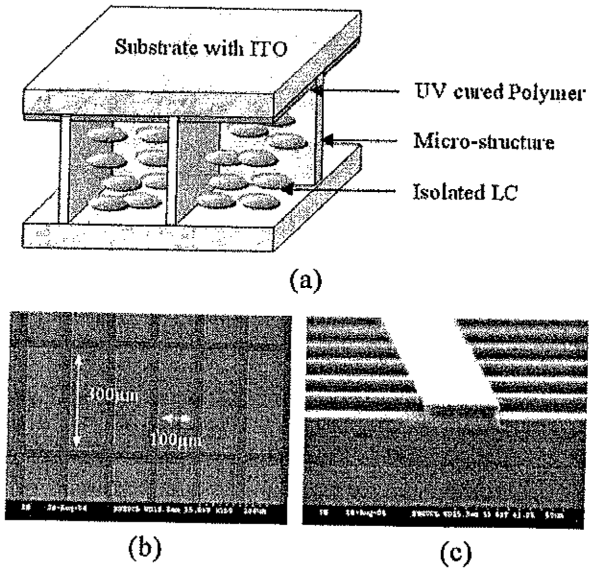


Fig. 1 (a) Schematic diagrams of the pixel-isolated LC device. (b) and (c) SEM images of the microstructures.

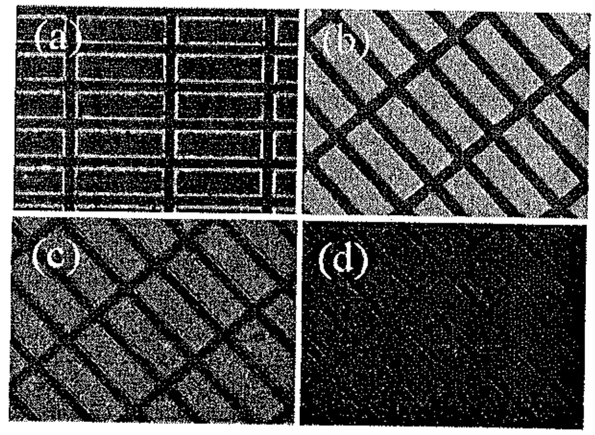


Fig. 2 Alignment textures of the sample under polarizing microscope. (a) is the microscopic texture when the rubbing direction of the sample is parallel to the polarizer. The microscopic images of (b), (c), and (d) are obtained at applied voltages of 0 V, 3 V and 7 V, respectively, after 45° sample rotation.

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 6.0 μm. The source of UV light was a Xenon lamp (λ=350 nm) operated at 200 W of electrical power. For complete phase separation to be induced, the molecular fraction of the pre-polymer should not be much [4-8]. With the ratio of our pre-polymer/LC composite, we can successfully isolate the LC molecules within the pixel, surrounded by the micro-structure and the uniformly solidified polymer layer. In the structure, the SU-8 microstructures support uniform cell gap from external shock. And the solidified polymer layer tightly attached the microstructure to the top substrate.

Figure 2 shows microscopic textures at room temperature after UV exposure under polarizing microscope. 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. Figure 2 (c) and (d) are show microscopic textures of the cell with applying 3 V and 7 V, respectively. We observed the uniform brightness in the pixel, so we can note that the polymer layers are solidified on the top substrates as a uniform film. The cross section and their shapes were further investigated using SEM. After opening the cell, that were rinsed with hexane for 24 hour in order to remove the liquid crystal and then dried. Figure 3 (a) shows SEM cross section images of cell. The image of bottom substrate as Fig. 3 (c) is the almost same as shown in Fig. 1 (b) without any polymerized texture. On the other hand, the image of top substrate as Fig. 3 (b) shows solidified uniform thin layer.

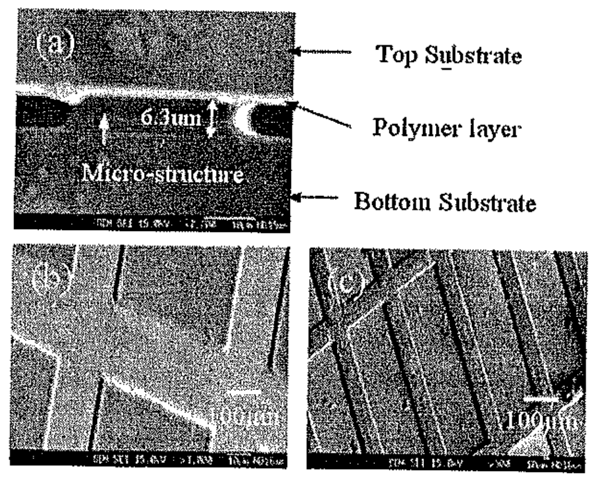


Fig. 3 (a) The cross section of the cell, (b) top substrate view, and (c) bottom substrate view.

3. Stamping Method for Pixel-Isolation in the Plastic LCDs.

In this section we propose a method to make stable plastic LCD by combination of stamping method for microstructure and anisotropic phase separation for adhesion of two substrates. The pixel-isolating wall structures are fabricated by stamping method using durable elastomeric poly(dimethylsiloxane) (PDMS), which is applicable to the roll-to-roll processing for mass production of large size flexible LCDs.

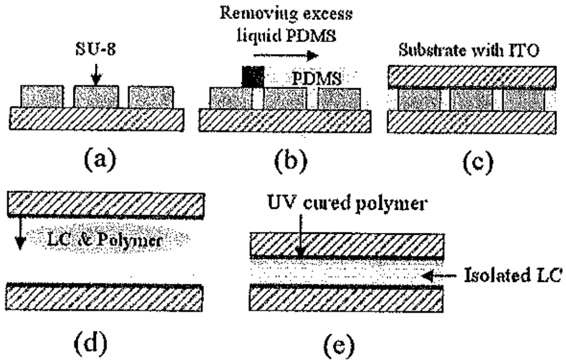


Fig 4. Schematic illustration of the fabrication process : (a) Master structure using SU-8 photoresist, (b) & (c) pattern transferring step, and (d) LC fabrication process, (e) the cross section of LCD cell after UV exposure.

Figure 4 shows the schematic illustration of procedures for fabricating our plastic LC device with the micro-transfer molding method. Onto the master substrate, liquid PDMS was dropped and the excess liquid PDMS was wiped out by a PDMS block as shown in Fig. 4 (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. 4 (c). Under pressing the covered ITO glass, the cell was baked 100 ℃ for 10 min. Then, the glass with 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 [9]. 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. 4 (d) and the coated surface was rubbed in a direction.

As a material to be filled into the prepared cavity, a mixture of NLC, E7 and UV curable polymer, NOA 65 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. 4 (d), UV light of $\lambda = 350$ nm was irradiated

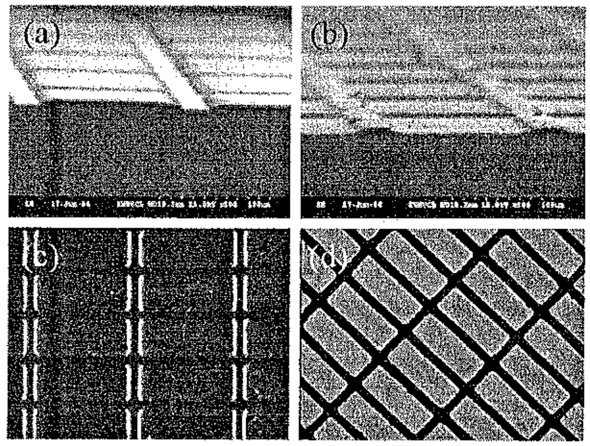
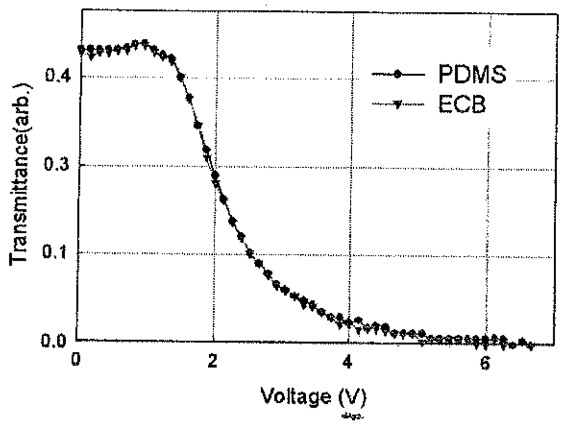


Fig 5. SEM images : (a) master structure of SU-8, (b) PDMS after pattern transferring, microscopic textures under polarizing microscope, (c) and (d) are black and white state images, respectively.

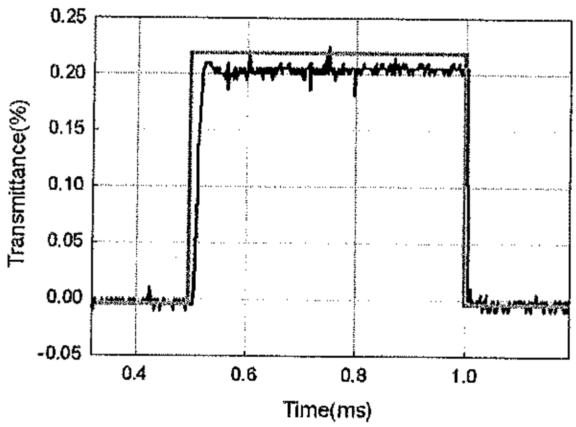
onto the bare ITO substrate to initiate polymerization. Finally, the LC molecules are isolated in the pixel surrounded by the PDMS wall structure and the solidified thin polymer layer. The micro-patterned PDMS walls act as supporting structures from external shock. Moreover, two substrates are tightly attached each other by the UV cured polymers.

Figures 5 (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 6 μm, respectively. It is clear that the patterned structure of SU-8 was well transferred to PDMS structure. The microscopic textures of our cell under the polarizing microscope are shown in Fig. 4 (c) and (d). Figure 4 (c) was taken when the rubbing direction of the bottom surface of the sample was parallel to one of the polarizers and Figs. 4 (b) were taken when the rubbing direction was rotated by 45° with respect to the polarizer.

Figure 6 shows electro-optic behavior of normal and PDMS samples. In both samples, transmittance as a function of applied voltage shows almost the same behaviors. The contrast ratio and response time are about 100:1 and 27 ms, respectively, which are comparable to those of normal sample without PDMS. Figure 7 shows the schematic diagram for roll-to-roll processing with the 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 substrate in



(a)



(b)

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

continuous process, the tight adhesion of two substrates can be achieved by the solidified polymer layer produced by UV exposure.

4. Concluding Remarks

We proposed a new method to produce tight adhesion of two substrates with stable LC structure using patterned microstructure and LC/polymer composite materials. The stable structure can be achieved by isolation of LC molecules into the pixel surrounded by microstructures. And two substrates are tightly attached each other by the solidified UV cured polymer produced by anisotropic phase separation from composite materials. The stable LC structure could be achieved by isolating LC molecules into the pixel surrounded by the micro-patterned PDMS wall structures. Using the interracial 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 later which could be uniformly produced using anisotropic phase separation from polymer/LC composite. Experimental results showed that our device had the 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.

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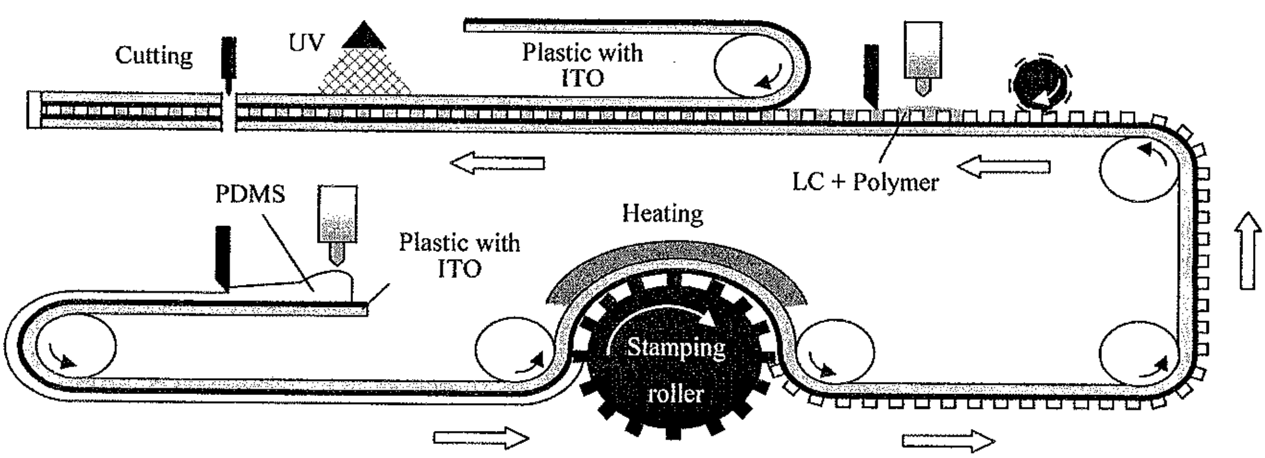

Fig. 7. Schematic diagram of roll-to-roll processing.

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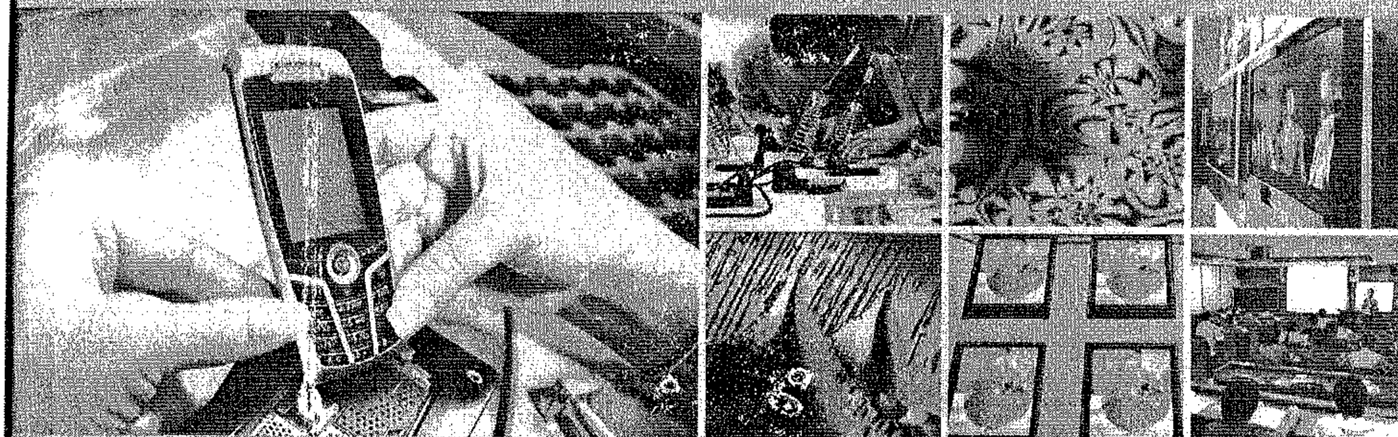

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