Method for tight adhesion of two Substrates in Pixel-isolated Liquid Crystal Structure for Flexible Display Application

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Abstract

We developed a method for adhesion of two substrates with stable liquid crystal (LC) structures using patterned microstructure and LC/polymer composite materials. 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 produced by anisotropic phase separation by UV exposure. 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.

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 lighter weight, thinner packaging, flexibility, and reduced manufacturing cost through continuous roll processing [1-3]. However, plastic substrates give rise to two big problems which do not 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[4-7]. However, 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.

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. 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 1D anisotropic phase separation from composite materials. This device shows not only good mechanical stability but also almost same optical behavior with respect to normal LC mode without microstructures.

2. Anisotropic Phase Separation Method for Adhesion of Two Substrates

Figure 1 is the schematic diagram of the proposed structure of pixel-isolated LC devices.

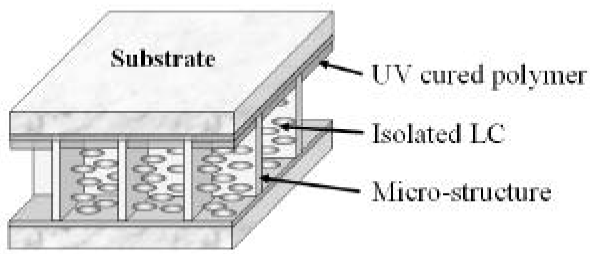
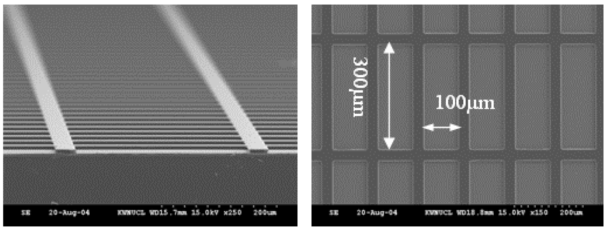


Fig. 1. The schematic diagram of the tightly bonded PILC structure.

The microstructure was fabricated on bottom glass substrate with ITO by normal photolithography method using negative photo resist SU-8 (Micro-Chem). Figure 2 shows scanning electron microscopy (SEM) images of the microstructure where polymer walls were patterned by UV exposure through a photomask.



(a) (b)

Fig. 2. SEM images of the microstructures (a) Side view and (b) Top view

The pixel size is 100 μm x 300 μm and the distance between pixels is 30μm. For the alignment layers, we used 2wt% Nylon 6(Aldrich) solution, that were spin coated on the micro-structure followed by rubbing to achieve homogeneous LC alignment. The materials used were E7 (Merck) for nematic liquid crystal (NLC) and UV curable epoxy NOA-65 (Norland) for pre-polymer. A solution of the LC and pre-polymer with weight ratio of 95:5 was dropped on the microstructure and covered by bare ITO glass substrate. The cell gap was maintained by the height of microstructure. In our case, we controlled the cell gap as 6.0 μm. However, with only these fabrication steps, the cell gap can not be stably kept from bending process since the attachment between the micro-structure and the bare ITO substrate is very poor. And also the structure is still weak for the external mechanical shock.

In our structure, such problems could be overcome by producing a uniformly solidified polymer layer onto the bare ITO substrate using a complete and an anisotropic phase separation of the pre-polymer/NLC mixture by UV exposure. The UV exposure was executed onto the bare ITO substrate. The solidified polymer layer makes strong attachment between the patterned wall structures and the opposite substrate and enhances the mechanical strength of the pixel-isolated LC device. Also, to avoid deterioration of electro-optic properties at displays, the uniform property of the polymer layer is essential. To obtain uniform polymer layer, some requirements in the fabrication condition should be satisfied such as the relative surface wetting properties between the pre-polymer and the LC molecules, UV intensity gradient, and the mixing ratio of the composite etc[4-9]. In our structure, the bottom substrate in Fig. 1 prefers the LC molecules to the pre-polymers since the LC molecules are completely wettable to the LC alignment layer where as the pre-polymers are partially wettable[4]. In addition, a sufficient intensity gradient is produced in the vertical direction of the sample since the UV light is predominantly absorbed by the LC molecules in the solution[4]. Consequently, NOA65 molecules first undergo polymerization near the top substrate in Fig. 1 and the LC molecules are expelled from the polymerized volume, forcing them to diffuse away from the UV source[4]. In our experiment, the source of the UV light of ? = 350 nm to initiate polymerization. The source of UV light is a Xenon lamp operated at 200 W of electrical power. For such complete phase separation to be induced, the molecular fraction of the pre-polymer should not be much. 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.

2.1 Alignment Textures & SEM images

Figure 3 shows microscopic textures at room temperature after UV exposure under polarizing microscope. It is clear that the LC is confined into the

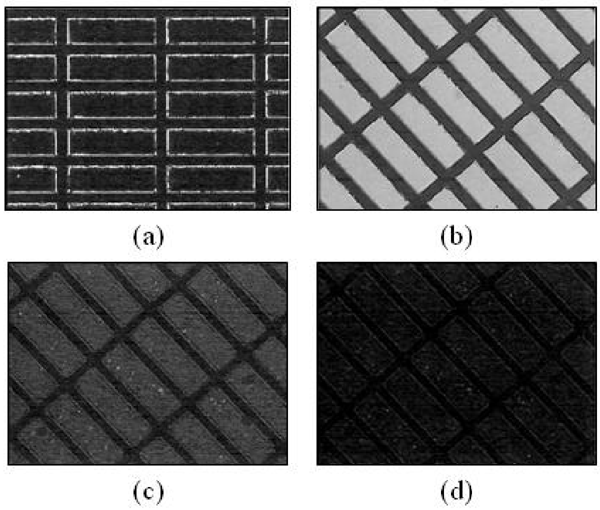


Fig. 3. Alignment textures of the sample under polarizing microscope. (a)Black and (b) white states without applying voltage and with applying (c) 3 V and (c) 7V, .respectively

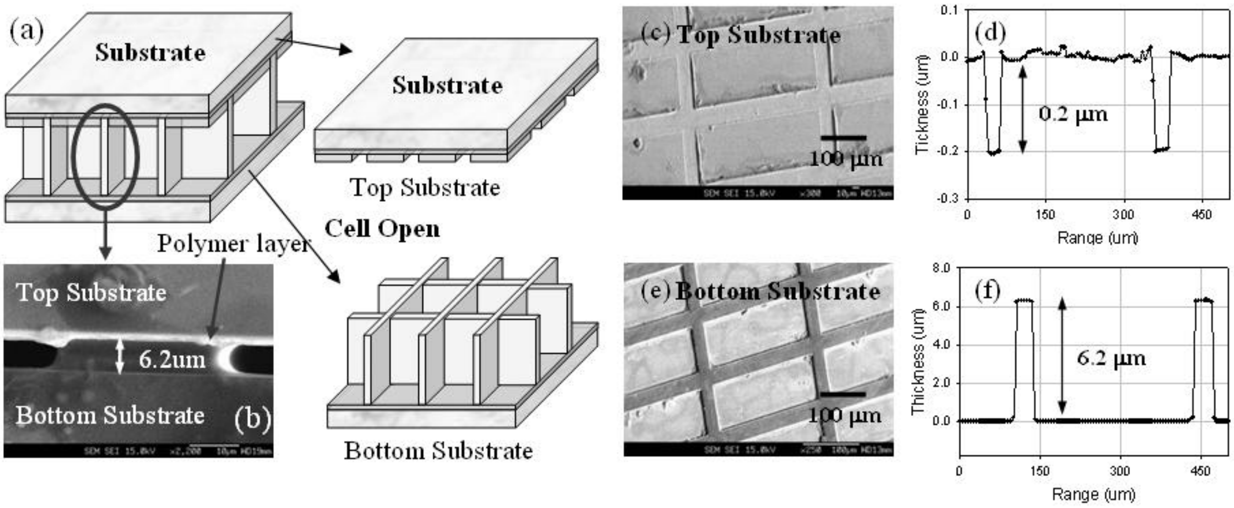


Fig. 4. (a) The schematic diagram and SEM images : (b) the cross section of the cell , (c) top substrate view, and (d) their surface profile , (e) bottom substrate view, and (f) their surface profile.

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 3 (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. To clarify, the cross section and their shape profiles were further investigated using SEM.

After opening the cell, that were rinsed with hexane for 3 min in order to remove the liquid crystal and then dried. Figure 4 shows SEM cross section images of cell. The image of bottom substrate as Fig. 4(c) is almost same as shown in Fig. 2(b) without any polymerized texture. On the other hand, the image of top substrate as Fig. 4(e) shows solidified uniform thin layer. Also, the surface profiles show the height of microstructures Fig. 4(e) and solidified polymer layer Fig. 4(f), respectively. It is clear that the polymer layer tear off at the attached point with microstructure in Fig. 4(d), and the cell gap is controlled by the difference between two layer thickness.

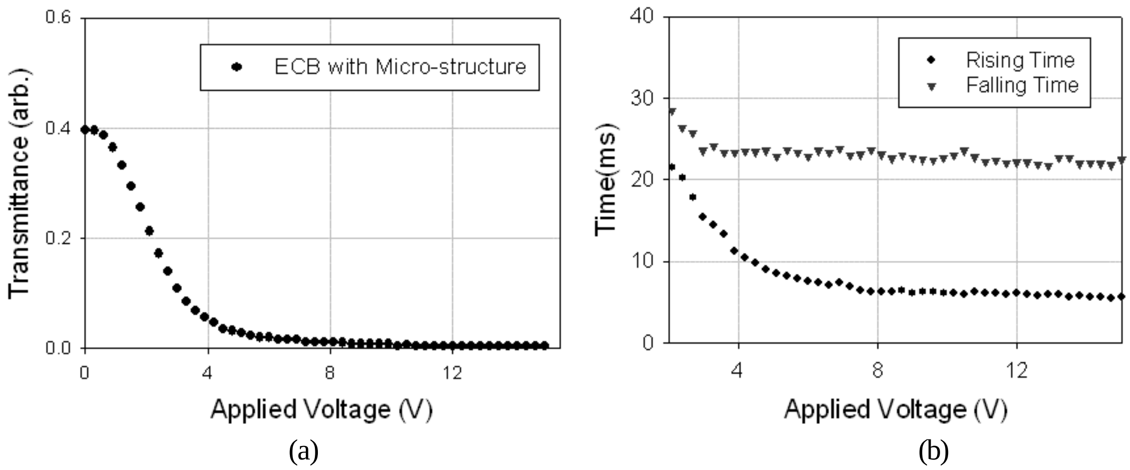


Fig. 5. Electro-optic properties : (a) transmittance and (b) response time as a function of applied voltage.

2.2 Electro-Optic properties

Figure 5 shows electro-optic behavior of the sample. The transmittance begins to decrease at about 0.5 V, and reach its minimum value at 10 V. It is possible to reduce the driving voltage by optimizing the concentration of pre-polymer, dielectric anisotropy of LC, dielectric constant of polymer, and overall cell gap. The maximum contrast is about 130:1 which is comparable to normal sample. The field driven and relaxation times are 5.5 ms and 22 ms at 10 V, respectively. The cell exhibits good switching characteristics at all gray levels.

3. 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. This device shows almost same optical behavior with respect to normal LC mode without microstructures. We believe that this method can be applicable to fabricate large size of plastic LCDs.

4. Acknowledgements

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5. References

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