Direct Formation of Bi-level Microstructures for Wide-viewing Liquid Crystal Displays with Plastic Substrates

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Abstract

We report on a wide-viewing liquid crystal (LC) display with bi-level microstructures spontaneously formed by selective wetting on a chemically heterogeneous surface. The bi-level microstructures serve as spacers for maintaining uniform cell gap, as well as protrusions for wide-viewing properties. Our LC cell having the bi-level microstructures shows good electro-optic properties.

1. Introduction

Recently, liquid crystal display (LCD) configurations based on plastic substrates have attracted much interest due to several advantages such as light weight, thinness, high durability, and cost-effective manufacturing. The plastic substrates have great potential for producing flexible LCDs, e.g., rollable LCDs for mobile appliances and the bendable LCDs for large-size applications such as high-definition television sets, personal computers, and public information displays. The use of plastic substrates, however, brings various issues on the reliability and image quality of the LCD in the bent environment.

Thus, many researches have been focused on improving the mechanical stability of the LCDs with plastic substrates [1-7]. However, the technologies to achieve high image quality have not been fully investigated yet. For improving the viewing angle characteristics of conventional LCDs based on glass substrates, the multi-domain alignment methods [8-12] are widely used because of high contrast, and reliability. However, the realization of multi-domains involves complex and elaborate wet processes for fabrication of protrusion structures or patterned electrodes that often result in structural damages on the plastic substrates. Therefore, a simple and wet etchingless fabrication method applicable for plastic substrates should be developed.

In this work, we propose a new method of fabricating a wide-viewing LCD with bi-level surface microstructures fabricated by selective wetting on a chemically heterogeneous surface. The bi-level surface microstructures are directly formed on a substrate through a simple spin-casting process without using any chemical etching process. The microstructures with two different heights serve as spacers for the uniform cell gap as well as protrusions that allow for wide-viewing property. Our LCD shows good extinction in the field-off state and self-aligned four different domains in the field-on state.

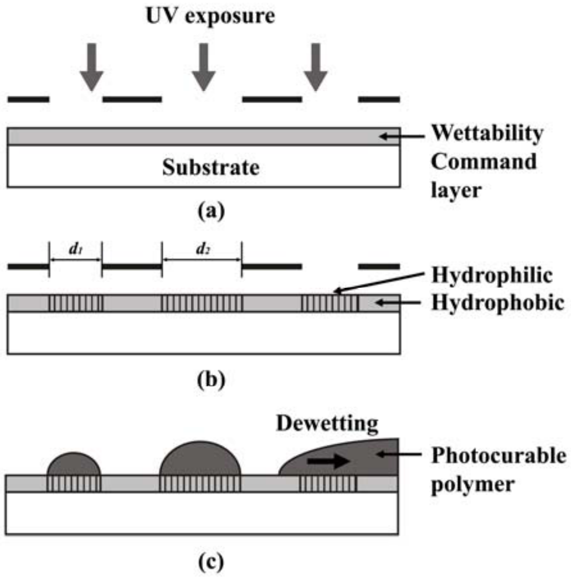

Fig. 1. A fabrication process of the bi-level surface microstructures: (a) the UV light irradiation through a photomask on a substrate, (b) a selectively patterned surface of the wettability commanding layer, and (c) a photopolymer confined in the hydrophilic regions after a spin-casting process.

2. Experimental

We first describe the fabrication process of spontaneously forming the bi-level surface microstructures as shown in Fig. 1. Under the UV irradiation through a photomask, the wetting property of the alignment layer is selectively modified so that a substrate having heterogeneous wettability is prepared [13]. By simple spin-casting of a photopolymer (NOA65, Norland Ltd.), we produced the bi-level microstructures where the lower-level structures behave as microprotrusions and the higher-level structures provide spacers.

For creating the heterogeneous wettability on the substrate without using any chemical etching process, a homeotropic LC alignment layer (JALS-684, Japan Synthetic Rubber Co.) was first spin-coated onto an indium-tin-oxide (ITO)-deposited plastic film substrate at the spinning rate of 3000 rpm for 30s, and subsequently cured at 120°C for 1 hour. The alignment layer was then irradiated by the ultra-violet (UV) light (λ = 365 nm) at the intensity of 100 J/cm^2 through a photomask having an array of circular apertures with two diameters of d_1 = 100 μm and d_2 = 200 μm, as shown in Fig. 1(a). Then, a photopolymer was spin-coated onto the substrate having the heterogeneous wettability at the spinning rate of 3000 rpm for 100 s and cured by the UV light at the intensity of 6 J/cm^2 to form the surface microstructures. The measured heights of the bi-level microstructure using a surface profilometer (Alpha-step 500, KLA Tencor Co.) were about 3 μm and 1 μm as shown in Fig. 2. The polyimide of JALS684 was spin-coated one more time onto the microstructures to promote the homeotropic LC alignment. The substrates were assembled to fabricate an LCD with the cell gap of 3 μm. A nematic liquid crystal (MLC-6608, Merck) with a negative dielectric anisotropy was filled into the cell by capillary action. A polarizing optical microscope (OptiphotII-pol, Nikon) was used for observing microscopic textures of our LCD with bi-level surface structures. A square wave voltage at the frequency of 1 kHz was applied to the LC cell to measure the electro-optic (EO) properties using a light source of a He-Ne laser with the wavelength of 632.8 nm. A spatial photometer (EZ-contrast 160R, ELDIM) was used for measuring the viewing angle properties. All the measurements were carried out at room temperature.

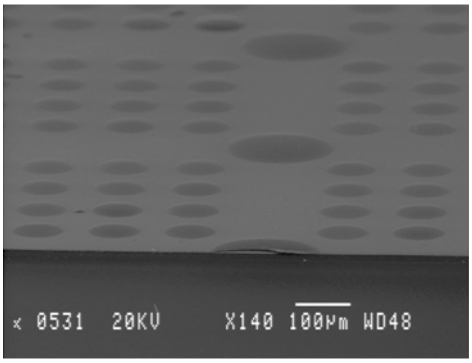

Fig. 2. A SEM image of the patterned bi-level surface microstructures.

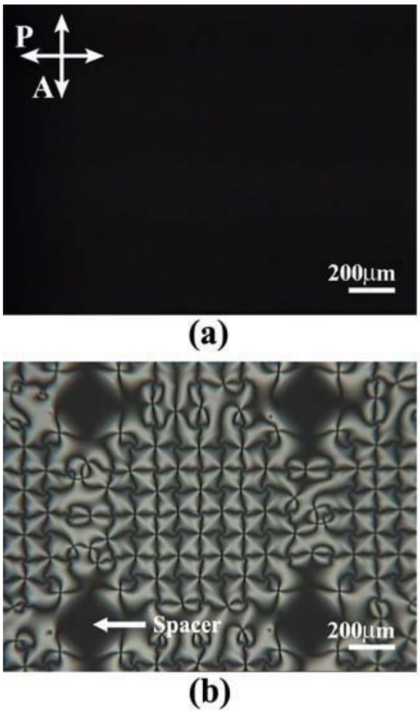

Fig. 3. Microscopic textures of our LCD observed under crossed polarizers at different voltages of (a) 0 V and (b) 3.2 V.

3. Results and discussion

Figure 3 shows the microscopic textures of our LC cell observed under crossed polarizers at different applied voltages of 0 V and 3.2 V. Under no applied voltage, the LC molecules were vertically aligned so that a dark state similar to a normal vertical alignment mode was obtained as shown in Fig. 3(a). When the voltage was applied, axially symmetric LC domains were generated around each bi-level surface microstructure as shown Fig. 3(b). This is due to the variations in the effective voltage across the LC cell. The effective voltage can be written as [12]

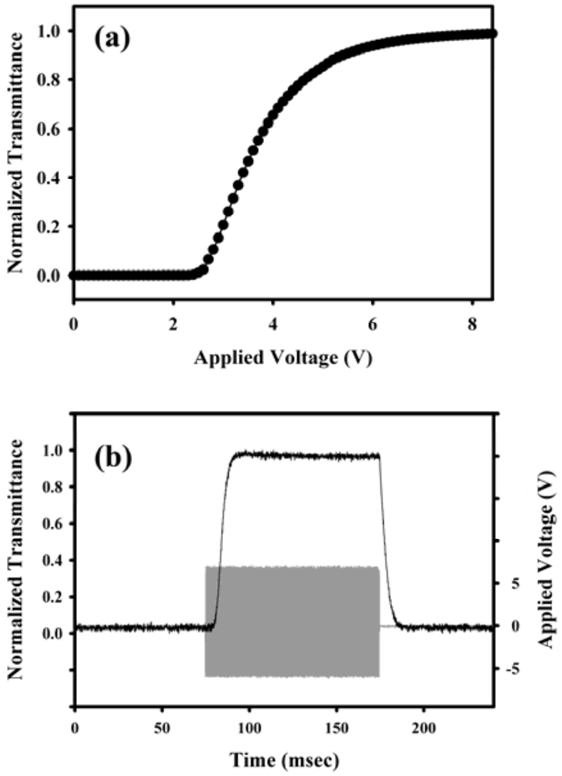

Fig. 4. (a) The normalized EO transmittance as a function of the applied voltage. (b) The dynamic EO response under the applied voltage of 6 V. The dark and gray lines represent the dynamic EO response and the applied voltage, respectively.

$$V_{eff} = V_{appl}(1+\frac{\varepsilon_{LC}h_{polymer}}{\varepsilon_{polymer}h_{LC}}) \quad (1)$$

In above expression, V_{appl} is the applied voltage, h and d are the thickness and the dielectric constant of relevant material at a local region, respectively. Since the difference in the effective voltages between the LC molecules on the surface microstructures and those on the substrate surface, the LC molecules are reoriented along the direction normal to the distorted electric field, thus axially symmetric four-domains are spontaneously formed.

Figure 4 shows the normalized electro-optic (EO) transmission and the response times of our LC cell having the bi-level surface microstructures. The EO transmittance began to increase at about 2.4 V and became saturated beyond 7 V as shown in Fig. 4(a). The contrast ratio was measured to be about 100:1. The dynamic EO response characteristics are shown in Fig. 4(b). The measured rising and falling times between the bright state and the dark state, defined as the switching times between 90% and 10% in the EO transmittance, were measured to be τ_{on} = 25 msec and τ_{off} = 13 msec, respectively. These EO properties are suitable for most of video applications.

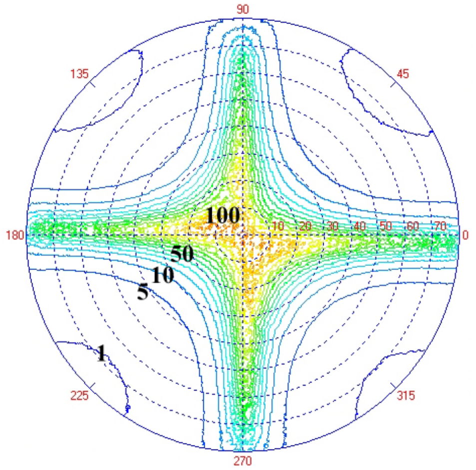

Fig. 5. The iso-contrast map of our LC cell having bi-level surface microstructures.

The viewing angle characteristics of our LCD are shown in Fig. 5. Symmetric viewing properties were achieved due to the self-optical compensation between four different domains as shown in Fig. 3(b). Wide-viewing characteristics up to the angle of ± 80° were obtained along both the vertical and horizontal directions even without any optical compensation film.

4. Summary

We developed a viable method of directly forming the bi-level surface microstructures for wide-viewing LCDs with plastic substrates. Based on the heterogeneous wettability, the bi-level surface microstructures for the spacers and protrusions are easily obtained through a single spin-casting process without using any elaborate chemical etching process. The self-aligned symmetric multi-domains were found to significantly improve the viewing properties of our LCD. Because of the simplicity and the uniformity over large area, the fabricating method used here has a great impact on developing a variety of flexible displays on plastic substrates.

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6. References

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